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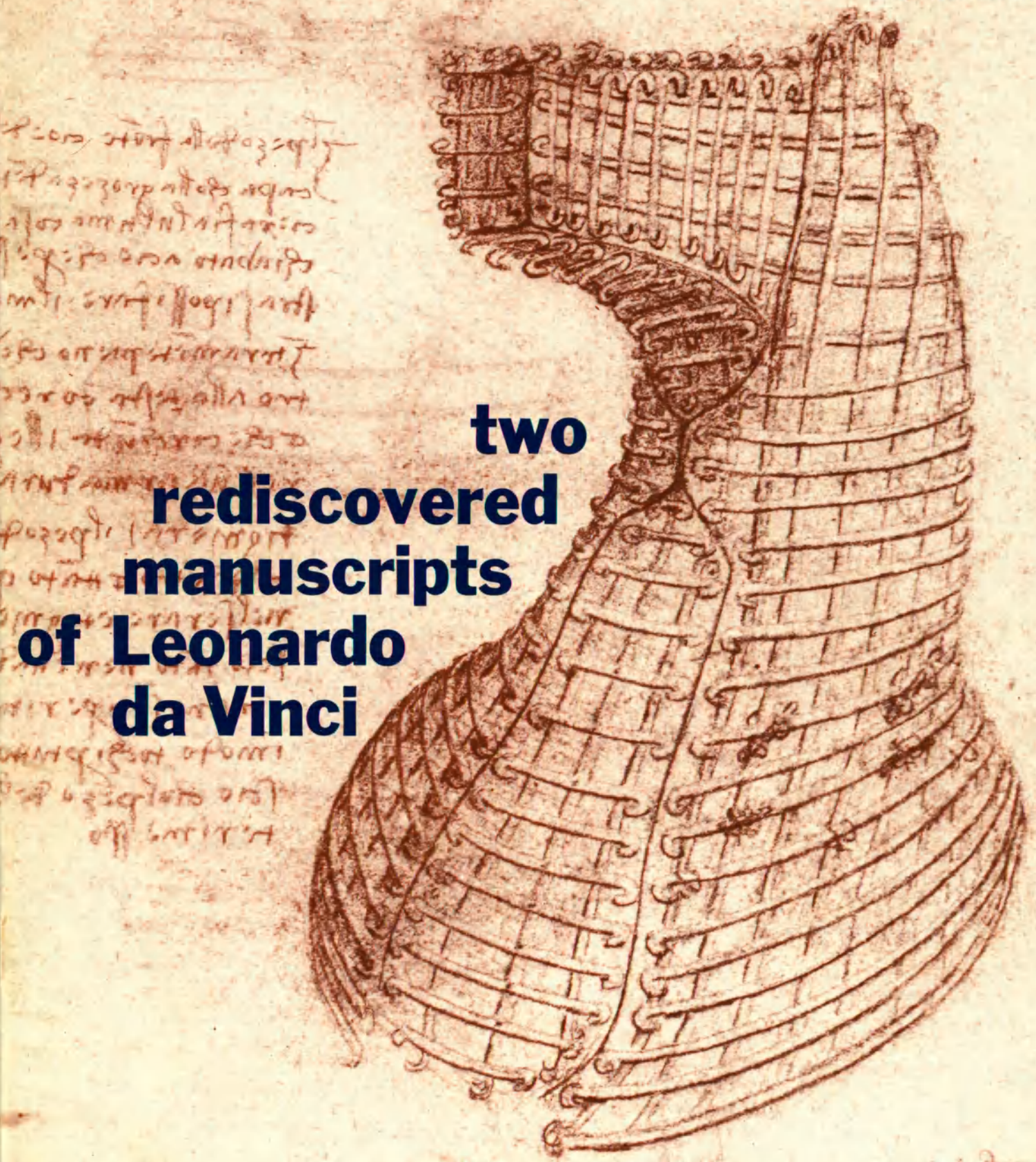

two rediscovered manuscripts of Leonardo da Vinci

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Photo © Giraudon, Paris

Treasures of world art

Florentine gracefulness

The extraordinary hands shown above are a detail from The Virgin of the Rocks **(left) which Leonardo painted in 1483. Upper hand is that of the Virgin Mary; below, an angel's finger points towards the infant John the Baptist. Leonardo was only thirty-one when he executed this masterpiece of the Italian Quattrocento, which today hangs in the Louvre, Paris (see p. 26). The figures have the natural gracefulness of 15th-century Florentine art and harmonize perfectly with the natural setting and the precisely rendered flowers and leaves. Some 23 years later (about 1506), Leonardo painted a second version of** The Virgin of the Rocks. **In this later version, which now hangs in the National Gallery, London, Leonardo made many changes: the angel no longer points his finger at the infant John the Baptist, and many of the details of rocks, vegetation and drapery are different from those in the 1483 painting.**

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TWO REDISCOVERED MANUSCRIPTS OF LEONARDO DA VINCI

Page

5 **THE STRANGE VICISSITUDES OF LEONARDO'S MANUSCRIPTS**
By Paolo Galluzzi

8 **THE MADRID NOTEBOOKS**
By Anna Maria Brizio

11 **THE ELEMENTS OF MACHINES**

15 **LEONARDO'S THEATRE IN THE ROUND**

16 **LEONARDO THE MUSICIAN**
By Emanuel Winternitz

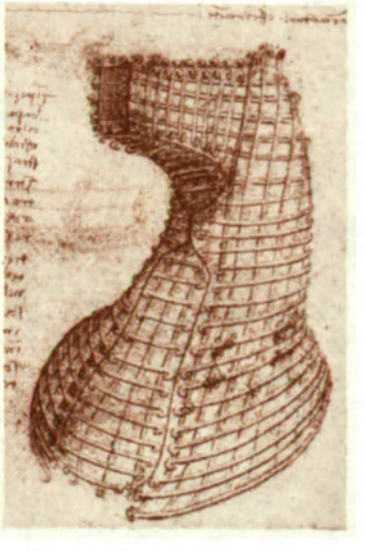
19 ***SPECIAL 16-PAGE SUPPLEMENT***
LEONARDO DA VINCI AS TOLD TO CHILDREN
By Bruno Nardini

37 **THE STORY OF THE COLOSSAL HORSE**

40 **LEONARDO AND THE STRIFE-RIDDEN RENAISSANCE**
By Eugenio Garin

45 **THE GLORY OF PAINTING**
Reflections on art in the Madrid II Manuscript
By Carlo Pedretti

2 **TREASURES OF WORLD ART**
Florentine gracefulness (Italy)



COVER

This is one of the most striking of the hundreds of drawings in two long-lost manuscripts by Leonardo da Vinci rediscovered recently in Madrid's National Library and now being published in facsimile for the first time. Drawing represents the head and neck sections of the outer mould of a colossal bronze equestrian statue which Leonardo undertook to execute (see full story page 37). Leonardo's mind was like a moving searchlight, constantly probing into the darkness, illuminating one subject, then rapidly passing on to another. Crammed with brief notes and sketches, done with unfailing precision, the Madrid notebooks give us a deeper insight than ever before into Leonardo's work in mechanics, military engineering, geometry, perspective, optics, casting, and many other subjects.

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Superimposed on a self-portrait of Leonardo from the Windsor Collection, England, is Leonardo's signature. He wrote, sketched and painted with his left hand, and most entries in his notebooks run from right to left in a curious "mirror" writing, as does his signature "Io Lionardo", here running across double page. Above it, Leonardo's signature written in the conventional way, from left to right.

Photo © Royal Library Windsor, U.K.

This issue is devoted to the work of Leonardo da Vinci as revealed in two long lost notebooks which were re-discovered in Madrid in 1965. Now known as The Madrid Codices I and II, **they constitute one of the great manuscript finds of the present century. This autumn a 5-volume facsimile edition of** The Madrid Codices **is being published, by arrangement with the Spanish government, by Taurus Ediciones of Spain, and McGraw Hill Book Company of the United States (1). The entire work was conceived and edited by a brilliant Vincian scholar, Ladislao Reti, who completed the transcriptions, translations (into modern Italian and English) and commentaries just before his death last October. Co-editions are being published in Italian, German, Japanese and Dutch. In the Foreword to** The Madrid Codices, **Luis Sanchez Belda, Director General of Spain's National Archives and Libraries, in Madrid, emphasizes "the broad spirit of international collaboration that has presided over the publication of the manuscripts: financed and directed by an American Company, the reproduction of the illustrations has been made in Switzerland, the composition in England, the editing in Italy and America, the printing in Spain, and the binding in the Fed. Rep. of Germany."**

At the same time, a lavishly illustrated 320-page volume entitled The Unknown Leonardo **(2), also edited by Ladislao Reti, is being published by McGraw-Hill and co-publishers in Spain, Italy, France, Fed. Rep. of Germany, Netherlands and Japan. Part of a chapter from this book is published on page 16 of this issue.**

Another unique Leonardo manuscript, the recently restored Codex Atlanticus **is now also being published in a 12-volume full-size facsimile edition by the Florentine publishers Giunti-Barbera and the Johnson Reprint Corporation (3).**

The Editors of the "Unesco Courier" wish to express their thanks to McGraw-Hill Book Company, Taurus Ediciones, and Giunti-Barbera for their generous help in making this special issue possible. All photographs, unless otherwise specified, are copyright and reproduced from Codex Madrid I and II.

THE STRANGE VICISSITUDES OF LEONARDO'S MANUSCRIPTS

by Paolo Galluzzi

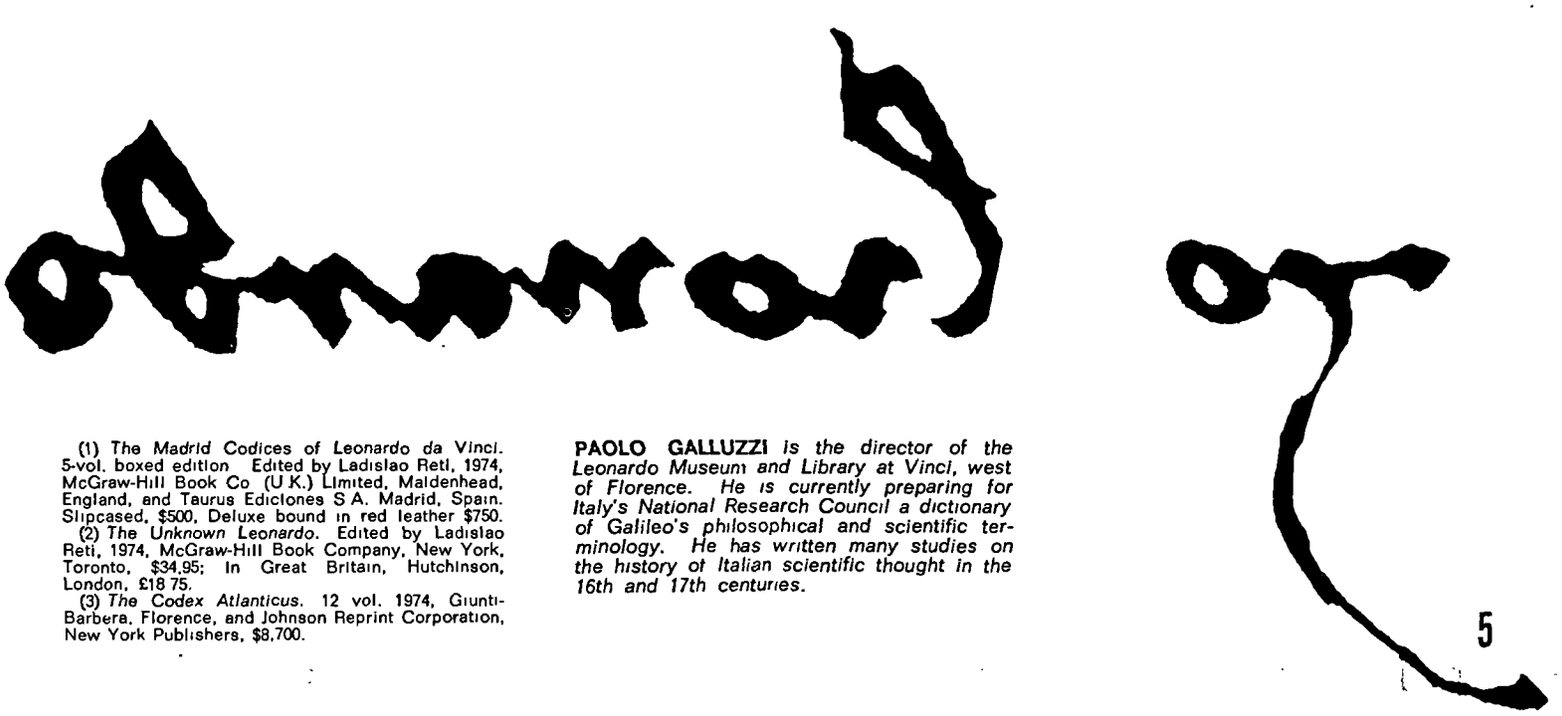
FOR almost three centuries, Leonardo da Vinci's mass of scientific jottings and sketches languished in obscurity. They were buried in notebooks and scribbling pads which were chaotically disorganized and hard to read. That is why, until the end of the 18th century, Leonardo's fame as an artist far surpassed his reputation as a scientist and engineer. Then too, after Leonardo's death in 1519, his manuscripts were first neglected and later split up and dispersed. Many of them disappeared forever.

In his will Leonardo left all his manuscripts to his faithful pupil Francesco Melzi, who had accompanied him on his travels and was present at his death-bed. Melzi transferred his precious inheritance to his villa at Vaprio d'Adda near Milan. After Francesco's death in 1570, his son and heir, Orazio, failed to see the significance of the Leonardo material and simply dumped it in the attic.

Thus it was an easy matter for Lelio Gavardi, the tutor in the Melzi household, to get his hands on thirteen Leonardo manuscripts. Gavardi went off to Florence with his prize, hoping to sell it for a high price to Duke Francesco de Medicis. However, incredible though it may seem, one of the Duke's counsellors advised his master that "These are not things for Your Excellency to bother with," and the sale did not go through.

Gavardi now abandoned his idea of selling the manuscripts and asked his friend Ambrogio Mazzenta, who was about to leave for Milan, to take them back to Orazio Melzi. However, Orazio did not want them and (according to the account in Mazzenta's memoirs) "was amazed that I had gone to all this trouble and made me a present of the manuscripts."

At this point, Pompeo Leoni of Arezzo comes on to the scene, and his role in the strange story of Leonardo's manuscripts is extremely important. Leoni, court sculptor to Philip II of Spain, showed great interest in the Leonardo manuscripts preserved by Francesco Melzi's heirs and managed to acquire many of them in exchange for promises of personal favours and protection. Leoni also got hold of ten of the thirteen notebooks given to Mazzenta by Orazio Melzi. Thus, in the eight years between 1582 and 1590, almost all Leonardo's papers passed to a new owner. ▶



(1) *The Madrid Codices of Leonardo da Vinci.* 5-vol. boxed edition. Edited by Ladislao Reti, 1974, McGraw-Hill Book Co. (U.K.) Limited, Maidenhead, England, and Taurus Ediciones S.A. Madrid, Spain. Slipcased, $500. Deluxe bound in red leather $750.

(2) *The Unknown Leonardo.* Edited by Ladislao Reti, 1974, McGraw-Hill Book Company, New York, Toronto, $34.95; in Great Britain, Hutchinson, London, £18.75.

(3) *The Codex Atlanticus.* 12 vol. 1974, Giunti-Barbera, Florence, and Johnson Reprint Corporation, New York Publishers, $8,700.

PAOLO GALLUZZI *is the director of the Leonardo Museum and Library at Vinci, west of Florence. He is currently preparing for Italy's National Research Council a dictionary of Galileo's philosophical and scientific terminology. He has written many studies on the history of Italian scientific thought in the 16th and 17th centuries.*

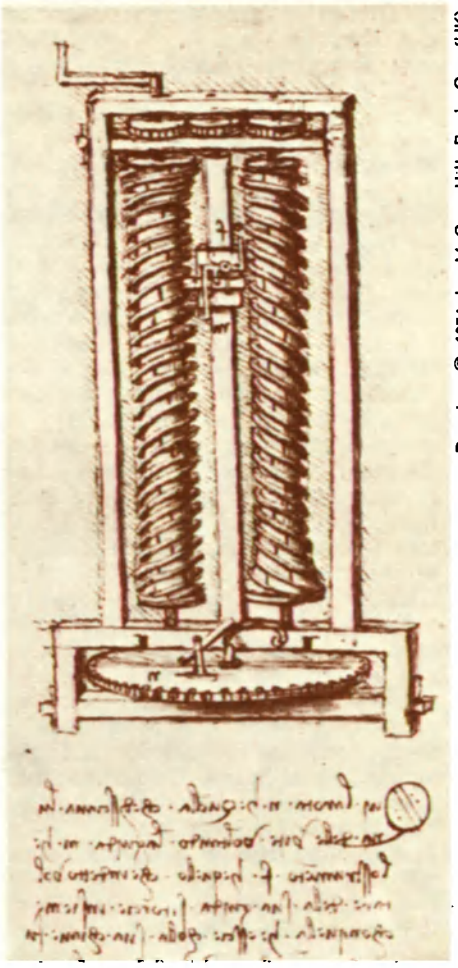
Leoni wanted to present the documents in a more attractive package, and therefore decided to split up several of the notebooks and rearrange them into large codices. But he was totally incompetent for this kind of work, and the net effect of his bizarre attempt at "restoration" was to alter the whole arrangement of Leonardo's papers and to destroy vital evidence as to when they were composed, in what order, the original number of notebooks, and so on. He also paved the way for a new Odyssey of loss and dispersion.

There is no evidence that Leoni carried out the intention which he expressed to Orazio Melzi of handing the Leonardo material over to Philip II of Spain as a gift. It appears that he only gave a sample of the documents to his royal patron and kept the rest for himself, since many of the manuscripts came into the hands of Polidoro Calchi, Leoni's son-in-law and heir, who put them up for sale.

Around 1622 Calchi sold the large volume compiled by Leoni and now known as the *Codex Atlanticus* to Count Galeazzo Arconati of Milan, and in 1636 Arconati gave this Codex (together with other Leonardo manuscripts) to the Ambrosian Library in Milan.

Other Leonardo documents which had been in Leoni's possession ended up in England. Thomas Howard, earl of Arundel, managed to acquire the second large volume of Leonardo papers compiled by Leoni. This is the collection of drawings now known as the Windsor Collection, since it is housed in the Royal Library, Windsor. Another manuscript (the present *Codex Arundel 263)* was also acquired by Thomas Howard and subsequently given by one of his heirs to the Royal Society. The earl of Arundel's acquisitions date from 1630-1640.

In the 18th century new "movements" of Leonardo manuscripts took place. Around 1715 Lord Leicester acquired



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Above, a drawing from Codex Madrid I, one of many in which Leonardo analyzes the basic elements of machines. This is a device for the transmission of power and motion through screws and wheels, a subject to which Leonardo continually returned.

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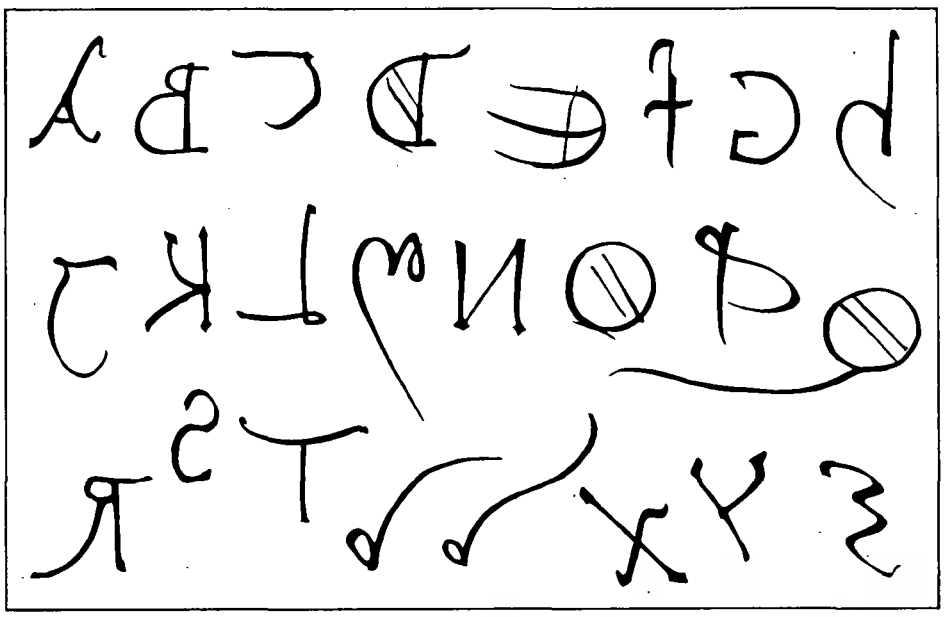
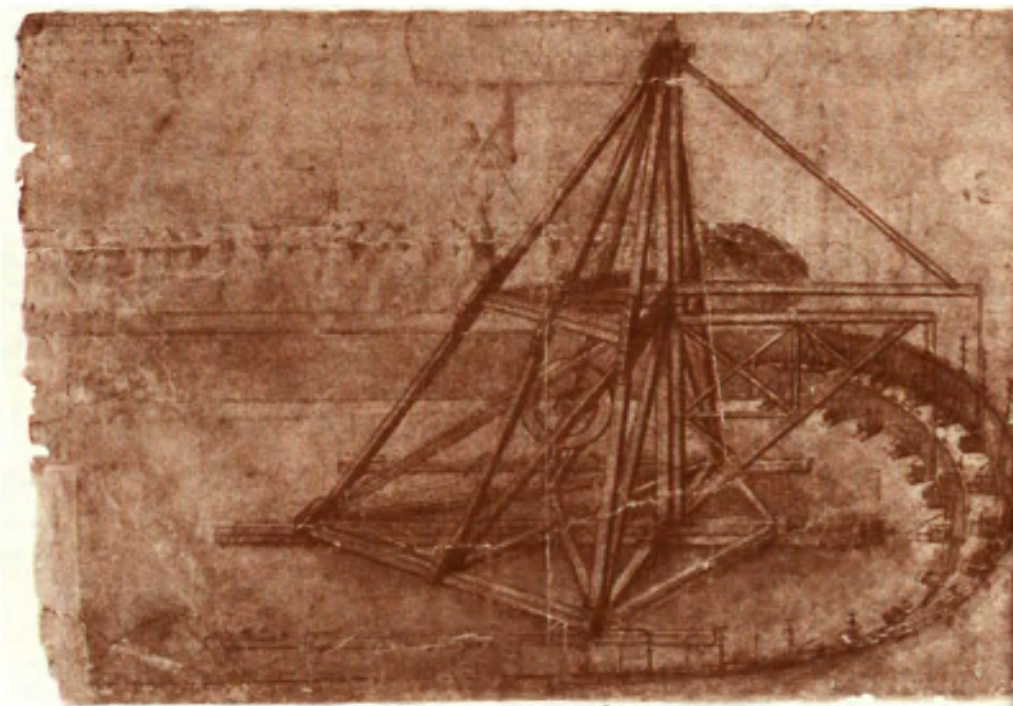


Above, capital letters of Leonardo's alphabet as he wrote them, backwards, mirror-fashion. They are enlarged from various pages in Codex Madrid I. Not all Leonardo's handwriting is as elegant as this, however. He often scrawled his thoughts haphazardly in the margins of his notebooks. Capital letters at the beginning of each article are reversed forms of above "mirror-writing" alphabet.



The big treadmill-powered machine depicted at right in a drawing from the Codex Atlanticus was devised by Leonardo for lifting and transporting excavated materials in the construction of a canal. In Leonardo's time, parts of the River Arno between Florence and the sea were not navigable because of tortuous bends and sudden changes in level. Leonardo had an abiding interest in changing the river's course into a canal in order to create a great waterway between Florence and the sea.

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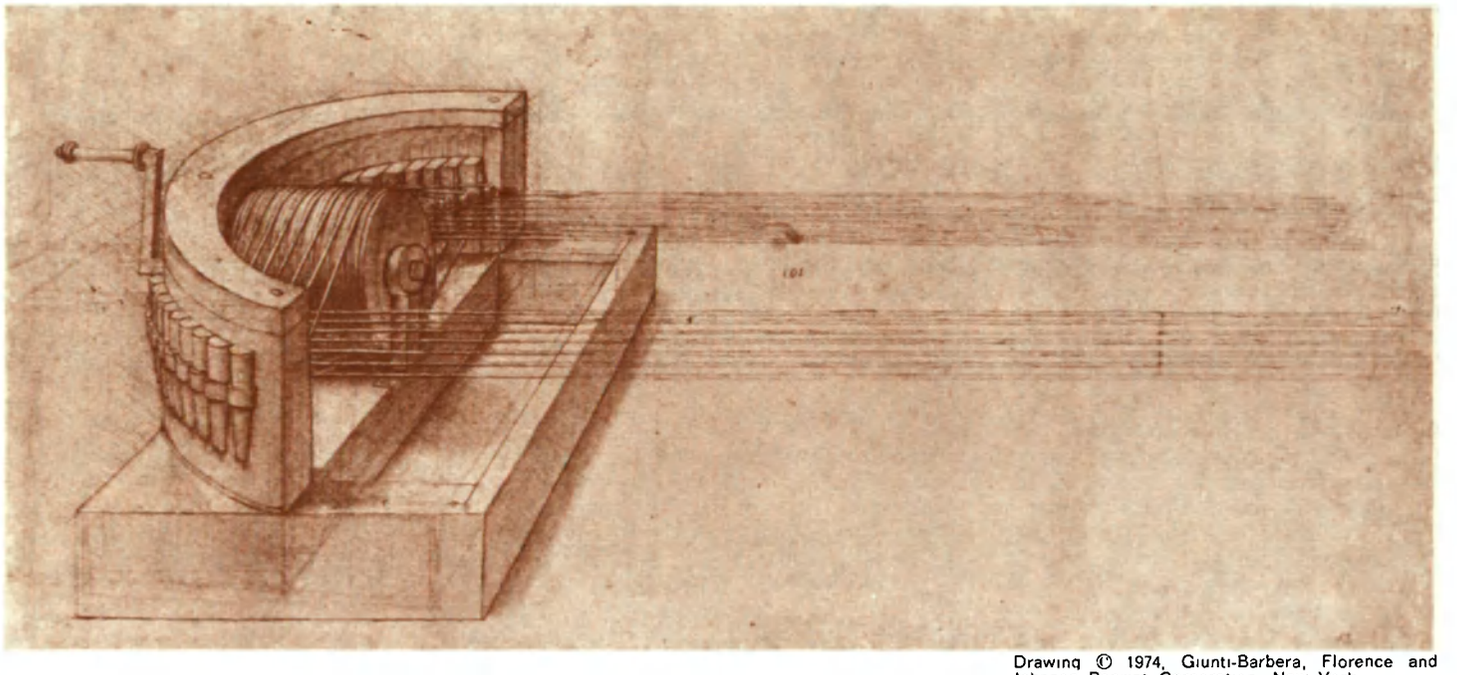

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and took back to England the Codex which now bears his name. Another manuscript, the so-called *Codex Trivulzianus* (notable for the long lists of words recorded in it by Leonardo) was back in the Ambrosian Library around the year 1750—Arconati had donated it to the Library and later removed it.

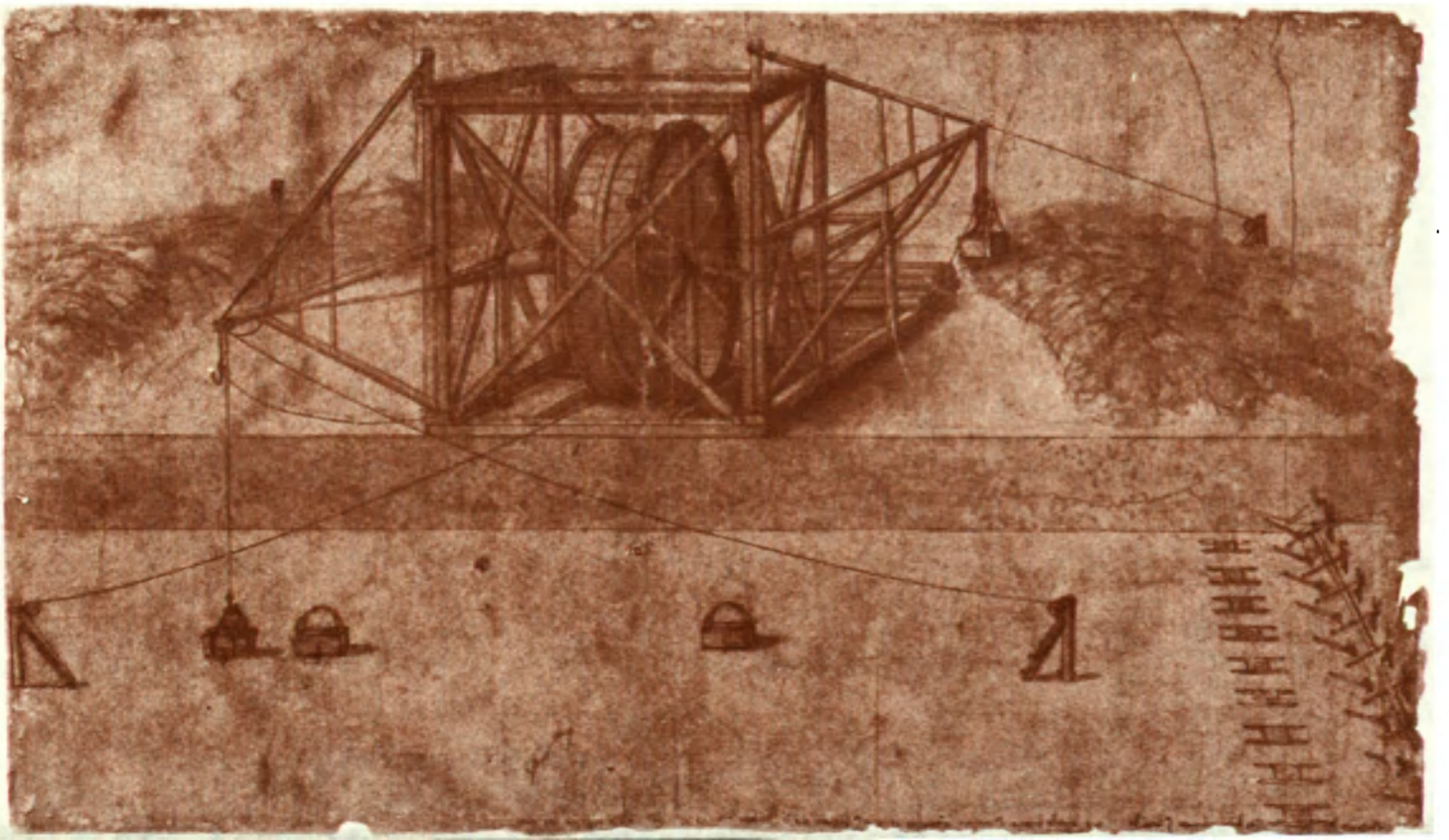
At the end of the 18th century even those notebooks which seemed to have found a permanent home started to move around again. During the Italian campaign in 1796-1797, Napoleon was ordered by the French government of that time, the Directory, to confiscate Italian art treasures and send them to Paris. The *Codex Atlanticus* and the manuscripts housed in the Ambrosian Library were among the major works which thus found their way to the French capital.

The *Codex Atlanticus* was deposited in the Bibliothèque Nationale, and the manuscript material was handed over to the Institut de France. Then at the end of the Napoleonic Wars the foreign governments involved managed to obtain the restitution of many of the art treasures which had been removed from their countries. The *Codex Atlanticus* was returned to Milan, but the Institut de France held on to the other Leonardo manuscripts.

In the 19th century English libraries enjoyed a new influx of Leonardo documents. In 1876, for example, John Forster gave the South Kensington Museum (now the Victoria and Albert Museum) the three Leonardo notebooks which are today known as the *Forster Codices*. However, after this generous gesture another extremely alarming episode occurred. Count Guglielmo Libri, a bibliophile and a pioneer of modern scientific historiography, became interested in Leonardo, and even thought of bringing out an

CONTINUED PAGE 50

The two drawings on this page are from the Codex Atlanticus, **a manuscript which has recently been magnificently restored by the monks of Grottaferrata convent near Rome. It is now being published in a 12-volume facsimile edition. Drawing above depicts a cord machine with fifteen spindles. Drawing below shows a machine for cutting a canal. It lifts the earth and then deposits it on the canal bank.**



THE MADRID

For Leonardo, drawing was a kind of language in images more immediate and telling than words. Drawing below, from Codex Madrid I, is one of several he made to demonstrate the impossibility of perpetual motion. As "The Unknown Leonardo" states, Leonardo was scornful of the seekers after perpetual motion and likened them to the alchemists who tried to convert base metals to gold.

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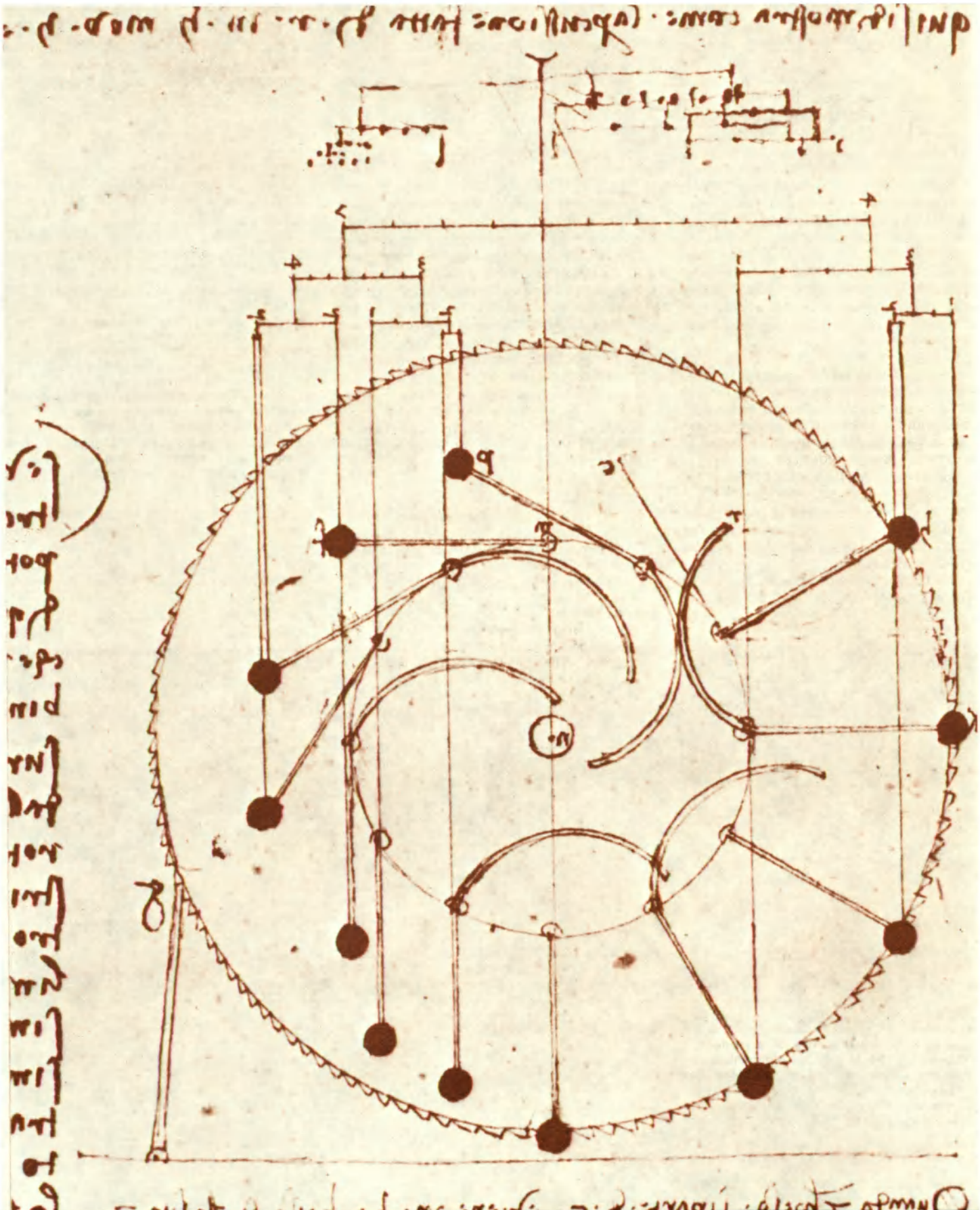


NOTEBOOKS

by Anna Maria Brizio

New aspects of Leonardo's genius emerge from his rediscovered manuscripts

THE recent discovery of two large manuscripts of Leonardo da Vinci, containing drawings and notes long thought to be lost, has opened up a new, exciting chapter on the work and thought of Leonardo, the Universal Man.

The new manuscripts form part of the extraordinary collection of notes and drawings into which Leonardo poured a lifetime of research, experiment and reflection on art and "natural philosophy" (science), on mechanics, geometry, anatomy, hydraulics, the motion of air and the mechanics of flight.

The two notebooks have added no less than 700 pages to the former total of 6,000 pages of Leonardo manuscripts. The Madrid Codices are rich in new information which now helps to clarify issues which have long been discussed by Leonardo scholars and left unsolved because of insufficient or fragmentary evidence.

Together, the new notebooks cover the fifteen-year period between 1491 and 1505 when Leonardo was at the peak of his creative activity. However, the two manuscripts differ from each other in subject-matter: *Codex Madrid I* presents an exceptionally uniform range of material and deals principally with mechanics, whereas *Madrid II* covers a wide variety of subjects, most of which have some connexion with art.

For example, *Madrid II* contains subtle notes relating to painting and deals with colour and colour effects. Extracts from some of these notes in fact appear in Leonardo's *Treatise on Painting* (compiled after his death). An entire section of the Codex is devoted to plans for casting the Great Horse of Milan, the equestrian statue of Francesco Sforza which Leonardo worked on for many years but which was never actually cast (see page 37). The Codex also includes a series of architectural sketches of fortifications.

When we are dealing with Leonardo, however, any distinction between artistic and non-artistic drawings is meaningless and indeed unjustified for he conceived of no such distinction in his work. His artistic and scientific activities always sprang from a single source, so that the conclusions reached in an artistic venture affected the development of a scientific project and vice versa.

Furthermore, Leonardo's drawings are always a living language endowed with extraordinary creative force and possessing the same clarity and elegance, whatever their subject-matter. The airy red chalk drawings of mountains in the Madrid folios are modern in their luminous and impressionistic depiction of landscape. It is interesting to note that they were in fact executed as part of a series of maps of the Arno river valley.

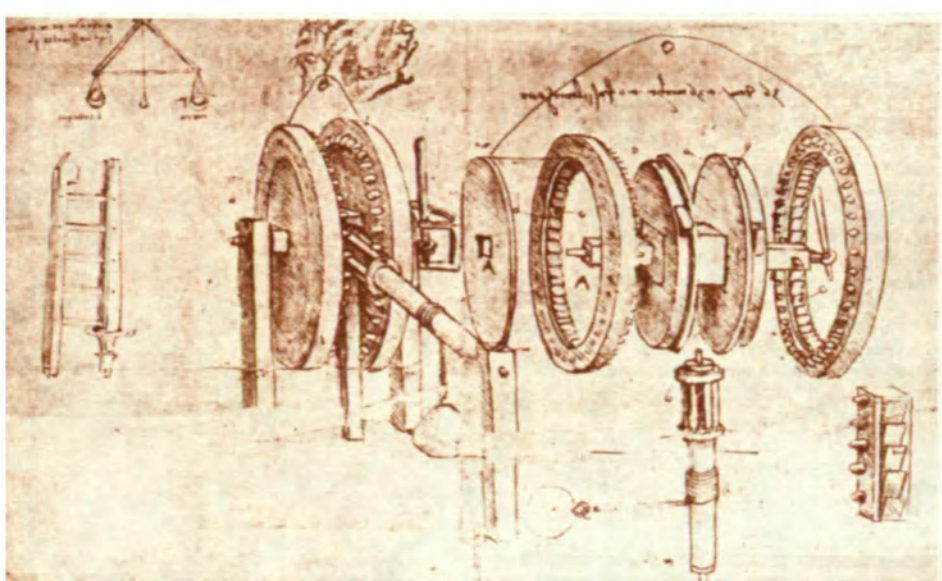
Again, the drawings of machines in *Madrid I* are so lucid and compelling that they suggest not only the surface appearance of the objects but also the dynamic force which makes them work. We get the same impression from Leonardo's anatomical drawings.

Of all the Leonardo notebooks which have come down to us, *Madrid I* is one of the most systematic (if such a word can ever properly be applied to Leonardo), perhaps because it is almost entirely devoted to a single subject—mechanics. In appearance too it is one of the most orderly, and many of its pages give the impression of being a definitive copy. On many pages the drawings are so neatly and carefully sketched and shaded, and the accompanying texts so impeccably laid out, that one wonders whether he was actually preparing them for publication.

The earliest and latest dates mentioned in *Codex Madrid I* are 1493 and 1497. However, I am personally inclined to place the work as a whole nearer to the earlier of the two dates, because of the numerous parallels with other Leonardo manuscripts from the early 1490s.

This was the crucial period of Leonardo's work in Lombardy, when he was applying himself with growing determination and success to both the theoretical and practical aspects of mechanics. His theoretical work centred on the definition of the "powers" (Leonardo uses the word "potenzie") which move the universe: weight, force, motion and impact. His practical work consisted in the application of these principles to the construction of mechanical devices. ▶

ANNA MARIA BRIZIO *is the president of the Ente Raccolta Vinciana (the famous Centre for the collection of Leonardo da Vinci's works) at Vinci, where Leonardo was born. She is a member of the Commissione Vinciana (Committee of Vinci studies) and the Higher Council of Fine Arts of Italy's Lincei National Academy. Professor of art history at the University of Milan, she is the author of many important studies on Leonardo da Vinci.*



Leonardo's drawing of a windlass to be used for hoisting heavy loads (right), is so precise as to be the envy of a modern draftsman. The assembled mechanism is sketched at left; at right, an exploded view of its wheels, discs and gears. Here Leonardo brilliantly resolved the problem of translating rotary to reciprocating motion.

Drawing © 1974 Giunti-Barbera, Florence, and Johnson Reprint Corporation, New York.

Some of Leonardo's most exquisite drawings in Codex Madrid I deal with the transmission of motion and power by means of toothed wheels, screws and levers. Mechanism shown above is an example of his constant efforts to design improved devices. Leonardo's diagram, above right, illustrates his explanation of the nature of accidental and natural motion. To demonstrate his theory he used as an example the pendulum effect produced when a weight suspended from a cord is allowed to fall and swing freely.

Leonardo set forth his ideas on the link between theory and practice in two famous maxims: "The book about the science of machines precedes the book of applications"; and "Mechanics is the paradise of the science of mathematics, because through it one reaches the fruit of mathematics."

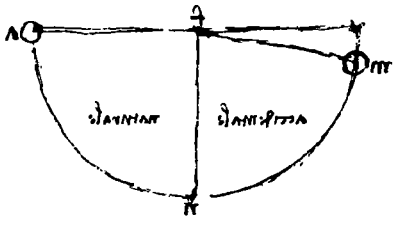
The most spectacular section of Leonardo's *Madrid I* manuscript is the part devoted to a detailed analysis and depiction of machinery, or more precisely, the components of various machines. This manuscript constitutes a kind of handbook of mechanics and gained immediate fame for the beauty and elegance of its drawings.

Ladislao Reti was the first Leonardo scholar to examine the Madrid notebooks at first hand. He spent years of passionate study on them, and drew special attention to the large number of innovations and ingenious solutions to mechanical engineering questions found in *Codex I*. Many of these are based on principles and techniques which are astonishingly in advance of his time foreshadowing developments made many decades or even centuries later.

From amongst the mass of observations on mechanical engineering contained in *Madrid I*, Reti underlines two themes which, he says, are worthy of exceptional interest because of their originality and the extensive treatment given them by Leonardo, namely, the motion of projectiles and the motion of the pendulum.

Leonardo divides motion into "natural motion" and "accidental motion", and analyzes their characteristics and the laws which govern them. Natural motion, in Leonardo's sense of the term, is dependent on the force of gravity: "All weights desire to fall towards the centre of the earth by the shortest possible path", writes Leonardo in his typical style in which he often personified things and events in Nature.

"Accidental motion", on the other hand, is caused by a force (Leonardo uses the word *potenzia, or* "power"), which opposes the object's "desire" to get as near to the centre of the world as possible. And "accidental" motion will be violent, says Leonardo. On the recto side of folio 147 of *Madrid I*, Leonardo analyzes the laws and behaviour of natural and accidental motion.



"We shall propose as example", he writes, "a round weight suspended from a cord, and let this weight be *a* (above, letters reversed). And it shall be lifted as high as the point of suspension of the cord. This point will be *f* . . . I affirm thus, that if you let this weight fall, all the motion made from a to *n* will be

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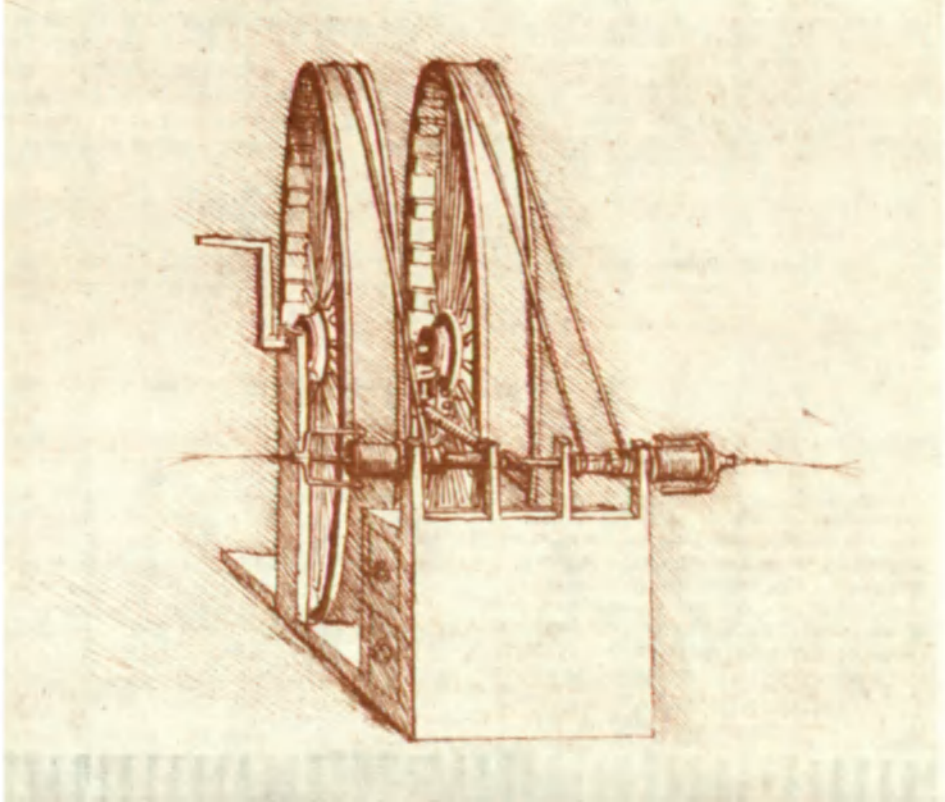
Right, Leonardo's drawing of flywheels equipped with a crank, for regulating the speed of a machine. Many of Leonardo's machines had built-in errors, according to Lord Ritchie Calder in his book "Leonardo and the Age of the Eye." Ritchie Calder recalls a newspaper article which pointed out that a tank devised by Leonardo would not have worked because Leonardo had arranged the crank in such a way that the front wheels would have rotated one way and the rear wheels the opposite way. "This was no error," says Ritchie Calder. "It was a deliberate mistake, typical of Leonardo's sardonic habit of putting a 'spanner in the works'. Was it mischief, or was it Leonardo's way of 'patenting' his ideas so that only he could make them?" Conducting research into Leonardo's technical work, Luigi Boldetti, a lecturer at a polytechnic in Milan, consistently found, working from Leonardo's diagrams, that there was frequently "something" which prevented the machine from working—an extra cog-wheel, a misplaced crank, or an unnecessary ratchet. When he had "debugged" it, the machine would work.



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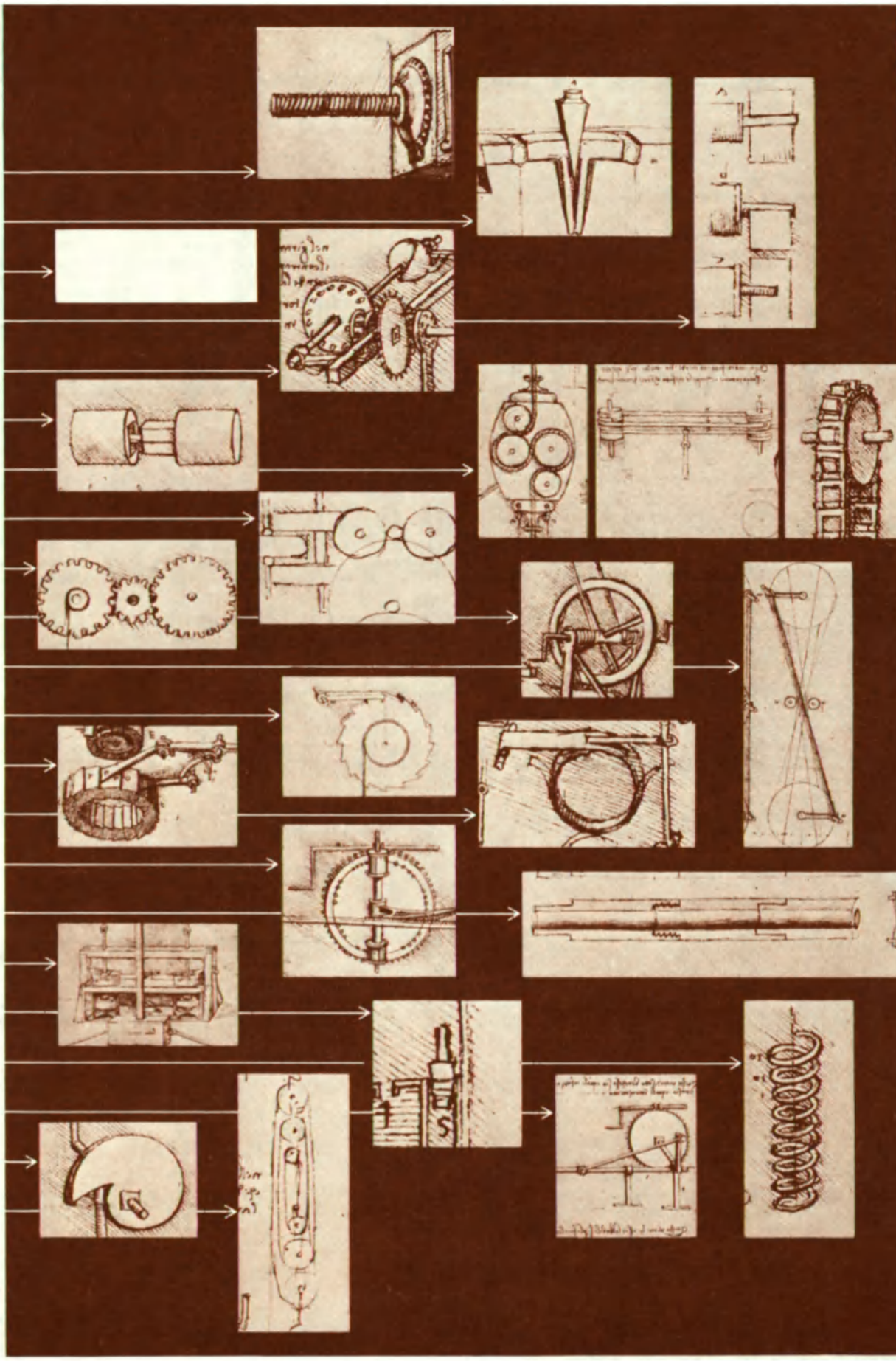


The elements of machines

In the Madrid Codices, Leonardo—for the first time in the history of technology—develops a systematic analysis of the concepts and elements of machines. In a chapter of the forthcoming volume, "The Unknown Leonardo", entitled "Elements of Machines", Ladislao Reti states that "Codex Madrid I proves beyond doubt that in this work Leonardo attempted to compose a true treatise on the composition and work of machines in general." Leonardo's understanding of individual mechanical elements as distinct from whole machines set him apart from other technologists of his time and from many who came after him. Previously scholars have held that it was not until the 1870s that Franz Reuleaux, in his classic work, "The Kinematic of Machinery", founded the modern theory of mechanisms. Codex Madrid I now establishes, in conjunction with a note found in the Codex Atlanticus on pump cylinders and pistons, that all the 22 elements of machines listed by Reuleaux were analyzed and studied by Leonardo, with the exception of rivets (which he purposely excluded). Chart above, reproduced from "The Unknown Leonardo", shows Leonardo's drawings in each case.

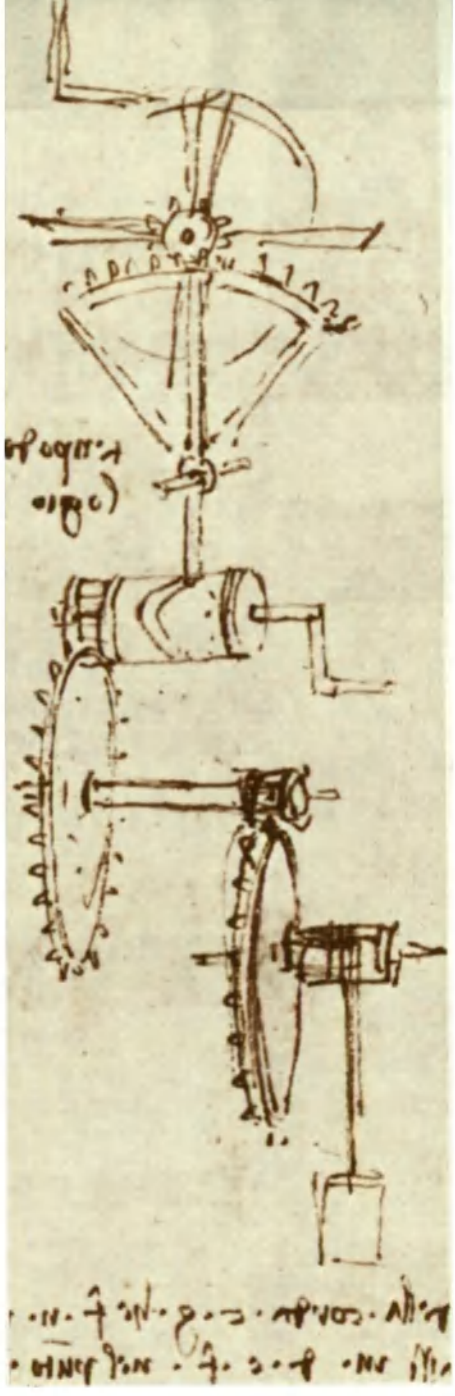
called natural, because it moves in order to approximate itself as near to the centre of the world as possible. After reaching the desired site, that is, *n*, another motion takes place, which we will call accidental, because it goes against its desire."

Leonardo next asserts that "Such accidental motion will always be less than the natural . . ." and "Consequently, natural motion, the more it approaches its end (from "a" to "n" as in the diagram) increases its velocity. Accidental motion (from "n" to "m") does the contrary."

In the same passage, Leonardo also analyzes the motion of a projectile launched in the air: "But if such motions are made towards the sky, as stones thrown in an arc, then the motion made by accident will be greater than the one we call natural . . ." and (in its return towards the ground after it has reached the zenith of its upwards motion) "the stone will cease to follow in the air the shape of the arc it began, *but, due to the great desire to go back down, it describes a line of much greater curvature and shorter than when it went upwards.*"

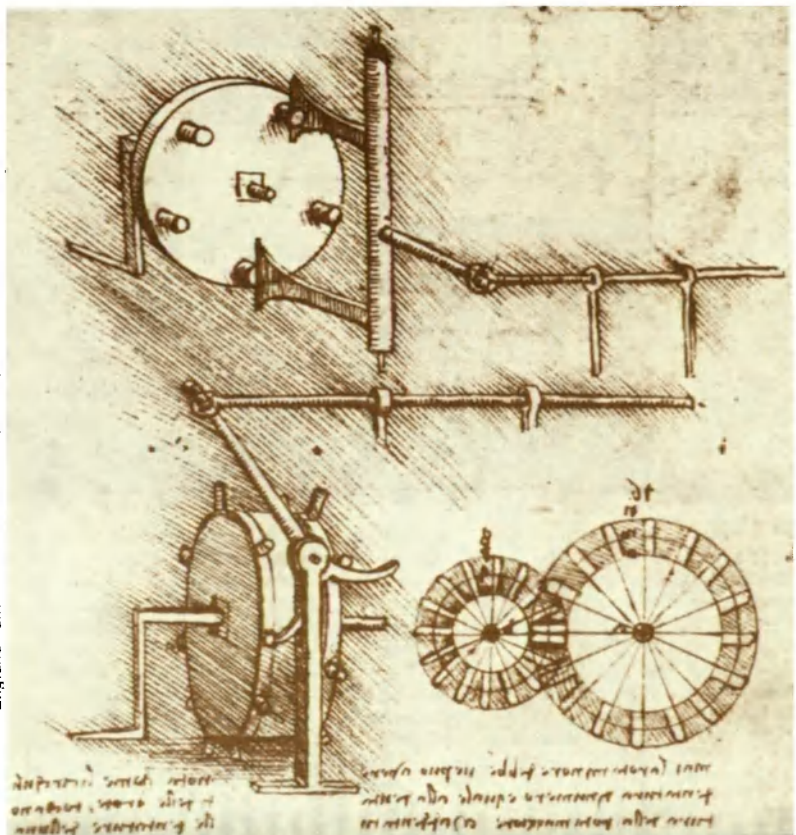
Almost a century later Galileo still believed that the line traced by the motion of projectiles in the air was a perfect parabola. With his sharp eye, Leonardo had "seen", both literally and metaphorically, the real trajectory of projectiles and correctly depicted the curve in his drawings.

Leonardo had also correctly observed the motion of the pendulum. He had seen that when a pendulum swings, the arc of its upwards motion is shorter than its descending arc, and that this ascending arc becomes



Galileo in 1582 and Huygens years later are usually credited with the invention of a pendulum clock. However, Codex Madrid I **contains notations and drawings which show that Leonardo had the completely original idea of applying the pendulum to clocks, thus anticipating Galileo by nearly a century. Leonardo's drawings include a number of pendular escapements (the escapement is the device for regulating the motion of the wheelwork in a clock) and on one page (folio 157 verso) he drew the complete clock mechanism shown here (on left) with a counterweight using a cord wound round a drum wheel, a series of cog wheels, a cam and a fan escapement, assembling the elements here into an ideal mechanism. Other drawings on this double page illustrate Leonardo's lifelong research into time-keeping devices and the ingenuity he displayed in devising more efficient mechanisms for them.**

All the parts of a mechanical timepiece are described by Leonardo in Codex Madrid I. **However, he does not depict or describe complete clockworks except for the one drawing shown at right, depicting the general set-up of a weight-driven clockwork provided with striking mechanism. Many important parts are nevertheless missing.**



The spring as a power source for clocks was still only a few decades old when Leonardo devised a spring-making machine and devoted several pages of Codex Madrid I **to the production and use of springs, especially clockwork. In drawings, above, he illustrates several types of springs and shows how a clock spring is wound under tension with a key (bottom row). Left, another example of Leonardo's research on clockwork mechanisms: sketches for a pinwheel escapement. Leonardo does not indicate the purpose of his escapement, but Galileo made use of the same device with a pendulum, and 24 years after his death a clock with such an escapement was installed in Florence.**

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Leonardo drew these sketches in Codex Madrid I to illustrate the working of toothed wheels and pinions. His notations, starting from the top, read as follows: "Here the wheel is unable to move the pinion but the pinion can move the wheel." "The same as above." "Again the same as above but only in part." "Here the pinion will move the wheel." "Here one moves the other."

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shorter as the oscillations of the pendulum become slower. Leonardo also realized that the smaller the arc becomes, the more uniform become the pendulum's oscillations.

We know about Leonardo's research into the possible application of pendular mechanisms to drive saws, pumps, and especially mill-wheels. But did he ever think of applying the pendulum to clocks? This question has been much debated, but never fully resolved.

In many pages of the *Madrid I Codex*, however, Ladislao Reti found a significant number of notations and drawings by Leonardo which he carefully analyzed and found to be studies for the adaptation of the pendulum to a clock escapement. Reti's arguments were sufficiently impressive to convince Silvio Bedini, one of the world's great experts on clockwork. The two scholars have written an entire chapter on the subject for the book *The Unknown Leonardo* amply illustrated with reproductions from Leonardo's *Codex Madrid I*.

Leonardo was always interested in time-keeping devices. He shows a clear knowledge and deep curiosity in the large clocks and planetariums that existed in Lombardy at that time. He was particularly interested in the clock in the tower of the Abbey of Chiaravalle near Milan, and the astronomical clock (or *astrarium)* by Giovanni de' Dondi in the ducal library of the Visconti Castle at Pavia, and made many sketches of their highly complicated parts.

Bedini and Reti point out that certain pages of the *Madrid I Codex* (folio 9 recto, folio 61 verso, and above all folio 157 verso) contain conclusive evidence that Leonardo had the completely original idea of applying the pendulum to clocks, thus anticipating the research of Galileo in this domain (1).

On folio 9 recto, Leonardo draws a crown-wheel connected to a horizontal rod, driven by a drum with cord and weight. On folio 61 verso there are some exceptionally clear-cut drawings of two different kinds of pendular escapement, one with a horizontal tooth-wheel, the other with a vertical tooth-wheel.

Finally, on folio 157 verso there is a rapidly drawn sketch, but it depicts a complete mechanism with a counterweight using a cord wound round a drum-wheel, a series of cog-wheels, a cam with sinusoidal track, and a fan escapement. All these components recur repeatedly in various folios of *Codex Madrid I*, but here they are apparently assembled into an ideal mechanism.

Yet nowhere in *Codex Madrid I* did Leonardo actually draw a complete clock with a pendulum mechanism; on folio 157 verso, for example, there is no indication as to the motor required to drive the device.

However, it is characteristic of *Codex Madrid I* that Leonardo generally tends to sketch the individual component parts of a mechanism, in order to gain a clearer picture of its structure and the way it works, rather than to make a final drawing of the fully assembled model. In the drawing on folio 157 verso we are fully entitled, according to Bedini and Reti, to see the first ever project for a pendulum clock—almost a century before Galileo!

All kinds of other mechanisms are analyzed by Leonardo in *Codex Madrid I:* springs for driving time-keeping

CONTINUED PAGE 36

(1) *Editor's note:* Professor Joseph Needham, in Volume IV, Part II of *Science and Civilisation in China,* devotes over 100 pages to an account of China's six centuries of mechanical clockwork which preceded the clocks of the 14th century in Europe. He particularly points out that the key invention in clockwork, the escapement, was devised as early as 1088 for an astronomical clock built by a Chinese scholar and civil servant, Su Sung.

A study of the proportions of the eye and eye-lid. Detail from a manuscript in the Royal Library, Turin.

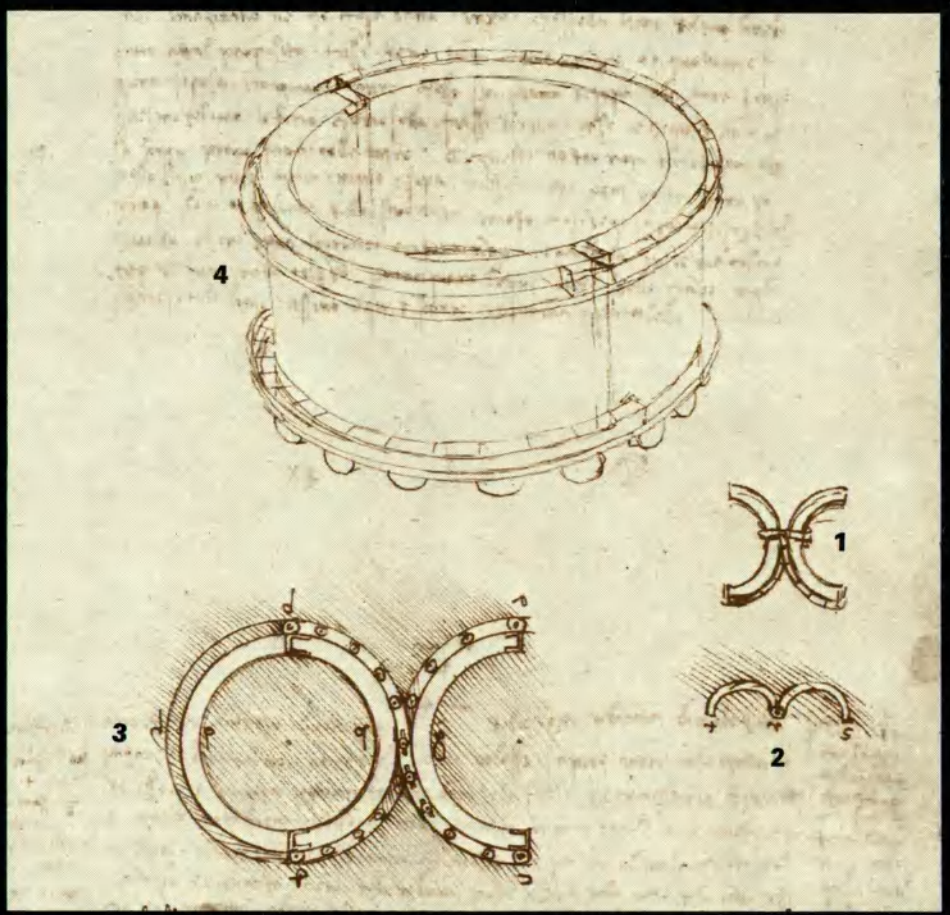
Photo © Royal Library, Turin

Leonardo's theatre in the round

Leonardo was a brilliant and enthusiastic organizer of shows and spectacles of various kinds. The lavish entertainments he arranged at the court of Lodovico Il Moro in Milan (see page 25) were legendary, and in later life, when living at Amboise, he is known to have staged at least one spectacular show for King Francis I. He designed scenery and theatrical costumes as well as a revolutionary kind of theatre and the machinery to work it. Leonardo's theatre consisted of two semicircular amphitheatres which rotated around a pivot and then closed to form a complete circle. He took the idea from Pliny's Natural History, which says that a theatre of this kind existed in ancient Rome but does not describe how it worked. Leonardo worked out his own solution to the problem. He closed the two semicircular halves of his theatre into a circle using what he calls "chains of beams."

Bottom right, we show the diagrams of this ingenious system as Leonardo depicted it in Codex Madrid I. When open the theatre consists of two semicircles joined together in the form of a rounded X (drawing no. 1). The audience takes its seats, and when the theatre is full the chains at the back of each amphitheatre (see drawing no. 3) are hauled until the two amphitheatres are side by side (drawing no. 2). The walls then continue to move around the pivot until they meet to form a complete circle (drawing no. 4). This invention is not impracticable. An engineer named James E. McCabe has in fact constructed a model of this theatre in the round from Leonardo's instructions, thus proving that the mechanical principles on which it is based are correct. Top centre and centre, model of theatre shown in various positions. The same principle is also found in the toy held by child (top right) in painting by Bernardino Luini (1475-1532). Perhaps Leonardo took the idea of the chains which manipulate his theatre from a children's toy, just as he may have done for the helicopter (see page 30).

Photos © 1974 from "Leonardo da Vinci" a collective work published by Giunti-Barbera, Florence.



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LEONARDO THE MUSICIAN

by Emanuel Winternitz

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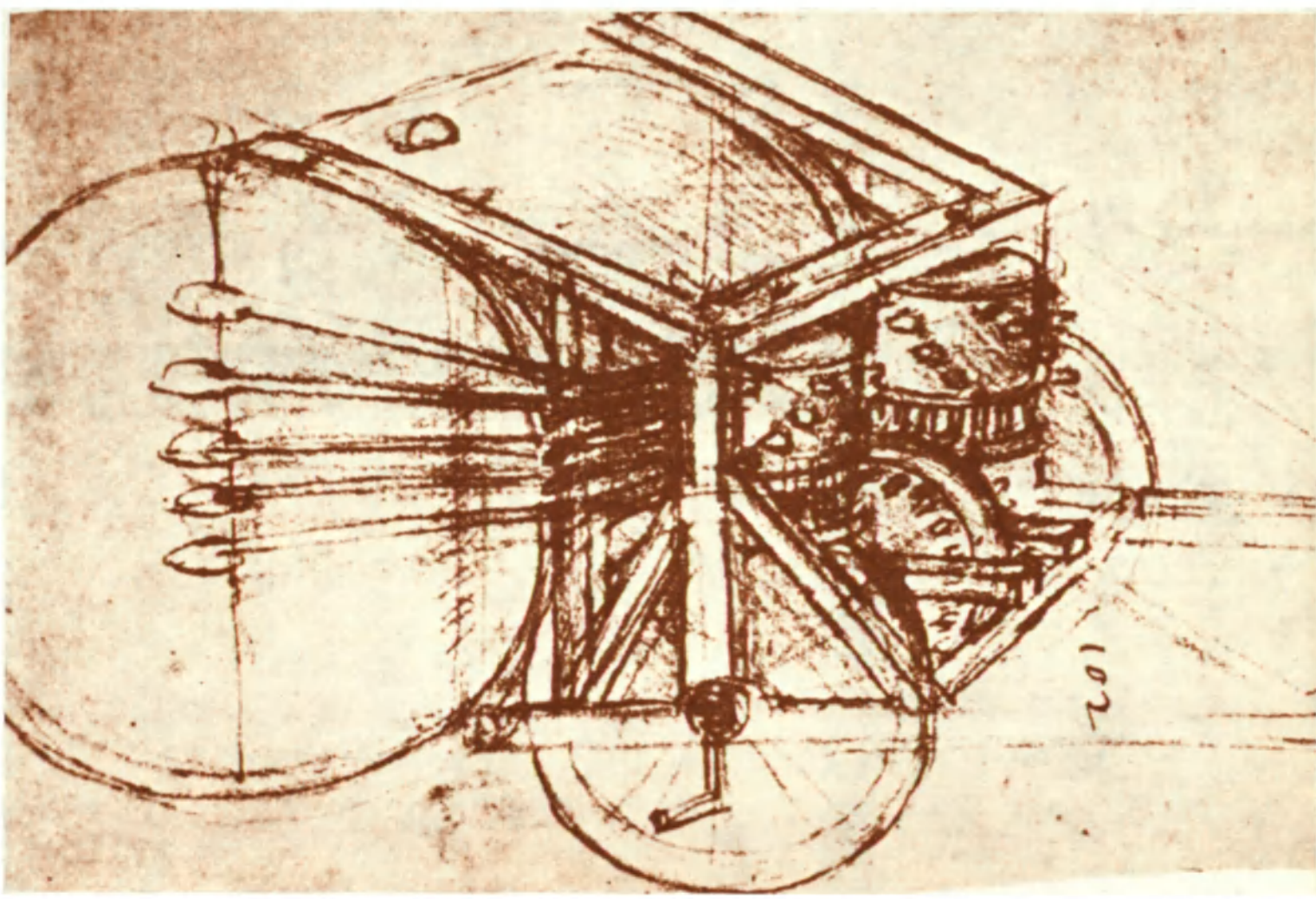
ALTHOUGH Leonardo has always been extolled as "the universal genius", his musical thought and his musical activities have received little serious attention and have never been treated systematically. It is characteristic that the standard works of Leonardo, even in our century, do not mention music at all, or content themselves with quoting remarks by Vasari, the author of the famous *Lives of the Painters*.

Leonardo was, in fact, profoundly occupied with music. He was a performer and teacher of music; he was deeply interested in acoustics and made many experiments in this field that had immediate bearing on music; he wrestled with the concept of musical time; and he invented a considerable number of ingenious musical instruments and made improvements on existing ones. He also had some highly original ideas about the philosophy of music that were intimately connected with his philosophy of painting.

Vasari records that "after Lodovico Sforza became the Duke of Milan, Leonardo, already famous, was brought to the duke to play for him, since the duke had a great liking for the sound of the lira; and Leonardo brought there the instrument which he had built with his own hands, made largely of silver but in the shape of a horse skull—a bizarre, new thing—so that the sound *(l'armonia)* would have greater sonority; with this, he surpassed all the musicians who met there to play. In addition, he was the



EMANUEL WINTERNITZ *is curator of musical instruments at the New York Metropolitan Museum of Art and is also visiting professor of music at City University of New York. This article is a condensation of a chapter entitled "Leonardo and Music", which will appear in the volume "The Unknown Leonardo", to be published this autumn by McGraw-Hill Book Company.*

best improviser of rhymes of his time."

A number of later historians also extolled his musical ability, notably the Milanese painter Giovanni Paolo Lomazzo, who in his *Trattato dell'arte della pittura* of 1584, and *Idea del tempio della pittura* of 1590, names "Leonardo Vinci painter" as one of the outstanding masters of the lira.

The lira mentioned in these sources was the *lira da braccio*, the most noble and subtle polyphonic bowed instrument of Leonardo's day—a fiddle with seven strings.

Leonardo inquired into the origin of sound ("What is sound produced by a blow?") and examined the sonorous impact of bodies upon bodies, expanding age-old Pythagorean notions. He investigated the phenomenon of vibration and sympathetic vibration, of how the percussion of a body makes it oscillate and communicate its oscillation to the surrounding air or to liquid or solid matter, for example.

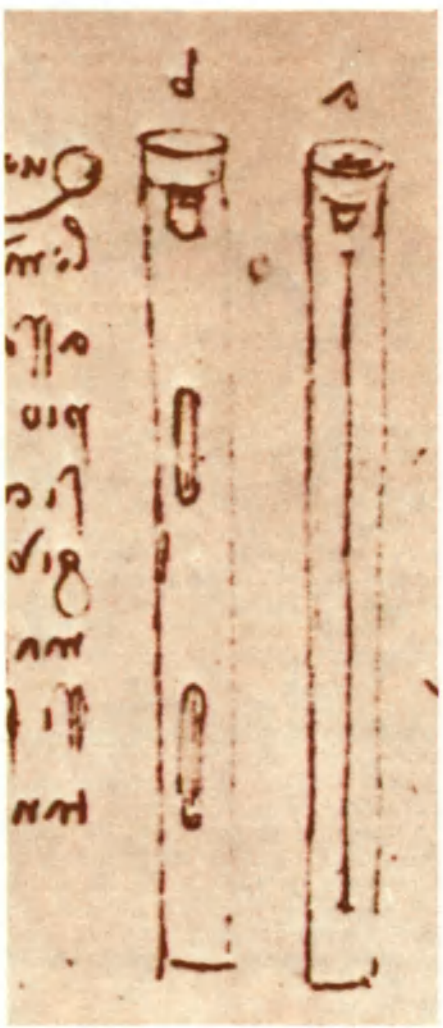
He studied the propagation of sound waves as differentiated from light waves, the reflection and refraction of sound waves and the phenomenon of echo, the speed of sound and the factors that determine degrees of loudness, investigating the laws that govern the fading of sound by varying the distance between its source and the ear.

Especially characteristic of his approach in this context is his establishment of what can be called a perspective of sound, parallel to the laws of optical and pictorial perspective so important to him as a painter.

Also, as a musician he was naturally occupied with the factors that determine musical pitch, and he experimented with vases of different shapes and varying apertures. Of musical importance, though Leonardo could not foresee its implication, was another of his observations: when he struck a table with a hammer, small heaps of dust formed on its surface; here Leonardo anticipated by three centuries the German physicist E.F.F. Chladni's discovery of the geometric sand figures produced by setting the edge of a plate in vibration with a fiddle bow.

Leonardo's notes and designs dealing with musical instruments are scattered in many of his manuscripts. Cryptic as many of these notes and drawings appear to be if studied in isolation, methodical comparison reveals that they are not merely diverting devices for performing magic tricks, but that they serve systematic efforts by Leonardo to realize some basic aims.

The most important of these aims are the following: automation of certain instruments and facilitation of playing technique through new kinds ▶



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Leonardo was a highly proficient musician. He invented some new musical instruments and improved others. He was deeply interested in the construction of drums and sketched many different kinds in his notebooks. He wanted to extend the musical possibilities of drums and also make them easier to play through various methods of automation. This drawing (opposite page) of a mechanized military drum in the Codex Atlanticus with its battery of drumsticks looks like part of a street musician's one-man band. The axle of the carriage wheel drives a central cogwheel which then turns other cogs which activate the five drumsticks on each side of the cylindrical drum.

Photo © Royal Library, Windsor, UK

In his work in art and science, Leonardo gave much attention to studies in anatomy, such as the drawing above of the larynx and trachea (now in the Windsor Collection). This probably inspired in him the idea for the two musical pipes, above left, in a drawing from the Codex Atlanticus. Leonardo wrote that the pipes changed their tone "in the manner of the human voice", and there is a close resemblance between upper opening of the larynx shown here and that of a recorder.

of keyboards; increasing the speed of playing; extension of tonal range to make it possible, for instance, to play melodies on drums; overcoming the quick fading of the sound of plucked strings, by giving the instruments an endless bow; enriching comparatively simple instruments to make them capable of polyphony or a wide range of successive tones; and even having a polyphony of the sounds of bowed strings at the control of a keyboard.

Leonardo was greatly interested in the construction of drums. He not only tried to make them easier to play but also expanded their musical possibilities, such as tonal range, far beyond the limitations of the conventional instruments of his time.

Leonardo endeavours to enrich the traditional function of drums by making them capable of producing chords and scales. For this he tries two different methods. One is the combination of several drums or skins of different pitch into one single instrument. The other consists of devices to make one skin produce tones of different pitch in rapid succession.

This aim is realized in various ways: either through the introduction of side holes, or through the use of scissor levers or screw devices to change the tension of the skin while it is beaten, or through slides that open and close a large hole in the resonating body, or, finally, through mechanisms that detach the skin cover from the body of a pot drum.

Among the many musical instruments contrived by Leonardo, the *viola organista* is by far the most complicated. No less than six different pages in the notebooks contain sketches for it.

The drawings are all concerned with the idea of a stringed instrument with keyboard, in which the strings are set into vibration by a mechanical device—a wheel, a bow with a back-and-forth motion, or a belt of hair moving across the strings as a sort of endless bow. Such an instrument would fill a big gap in the multitudinous array of instruments, not only in Leonardo's time but also in our own.

It would combine the polyphonic possibilities of the keyboard with the tone colour of bowed strings and thus would be something like an organ with string timbre instead of wind timbre, and in addition it would provide the possibility of producing crescendos and decrescendos by finger pressure.

Although it is not known in what order Leonardo made his sketches, it is possible to arrange the drawings in a logical sequence if we assume that Leonardo progressed from less workable solutions to more practical ones. In fact, he proceeds from an instrument with a bow moving back and forth across the strings, to one with a friction wheel, and finally to several versions of a revolving band of hair that sets the many strings into vibration.

The most workable, and apparently ultimate, solution is in Manuscript H, where we find a sketch of a perfectly consistent, workable keyboard instrument with an endless bow *(archetto)*, a belt of hair moved by a motor attached to the side of the sound box and passed across the strings by means of two small rollers. Leonardo also designed a mechanism permitting the player, by pushing the small projecting buttons, to select the desired strings and draw them against the *archetto*.

We do not know, however, how near Leonardo came to the actual construction of the *viola organista* or whether he ever made working models. Today, with an electric motor in place of one using weights or springs, the construction of the instrument would be greatly facilitated.

We must finally consider two instruments which have special interest because their invention seems directly inspired by Leonardo's anatomical studies; in fact they are applications of mechanisms Leonardo found in the human body. The first is in the *Codex Atlanticus*, where we find, among numerous small sketches for various machinery, drawings of two pipes.

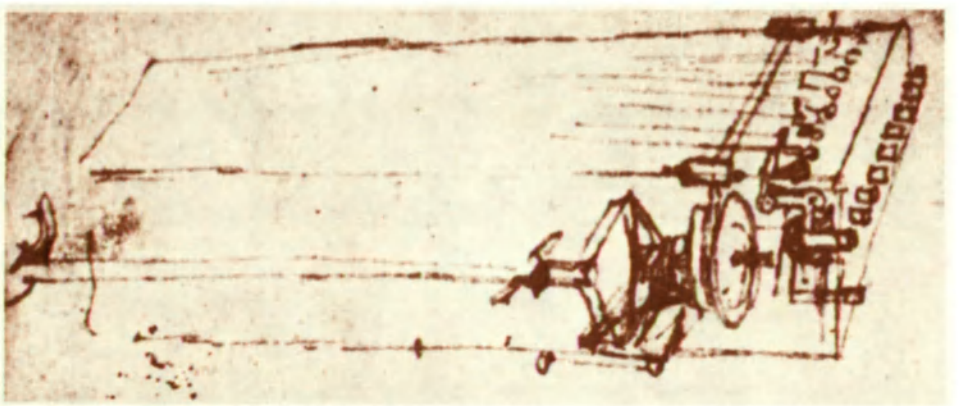
Every connoisseur of musical instruments will recognize immediately two recorders by their characteristic heads and mouth holes. Their basic structure has not changed substantially since Leonardo's time. Beneath the upper end held by the player's lips is a hole with a sharp edge which is struck by the air-stream emanating from his mouth.

Ordinarily recorders have on their sides six finger holes which are closed and opened by the fingertips of the player to produce the distinct tones of the scale. But Leonardo's recorders

CONTINUED PAGE 35

The ingenious drum design shown below in detail of a page from the Codex Arundel **is of outstanding importance because it allowed the drum's pitch to be changed while it was actually being played. By moving the scissor-like levers at either side of the square drumhead the player could tighten or slacken the drumskin. A drum whose pitch can be changed during performance did not appear in the West until the close of the 19th century.**

Codex Arundel © British Museum, London



The most complicated of the new musical instruments contrived by Leonardo was the viola organista, **a string instrument with a keyboard. We do not know how near Leonardo came to constructing it. The strings were to be set into vibration mechanically, and in his various notebooks Leonardo drew several devices for bowing many strings simultaneously. The most feasible and elaborate solution is in the sketch shown above, from a manuscript in the Institut de France. It shows a workable keyboard instrument with a belt of horsehair passing across the strings in an endless bow.**

Photo © Institut de France, Paris

In his typical way, Leonardo is here trying to obtain from a single bell sounds which could normally only be produced by four bells. The bell, sketched in Codex Madrid II, **is fixed; it does not swing. Two hammers strike its rim at opposite sides. Leonardo has noted: "The same bell will appear to be four bells. Organ keys with a fixed bell. And when struck by hammers, there will be a change of tones as in an organ."**

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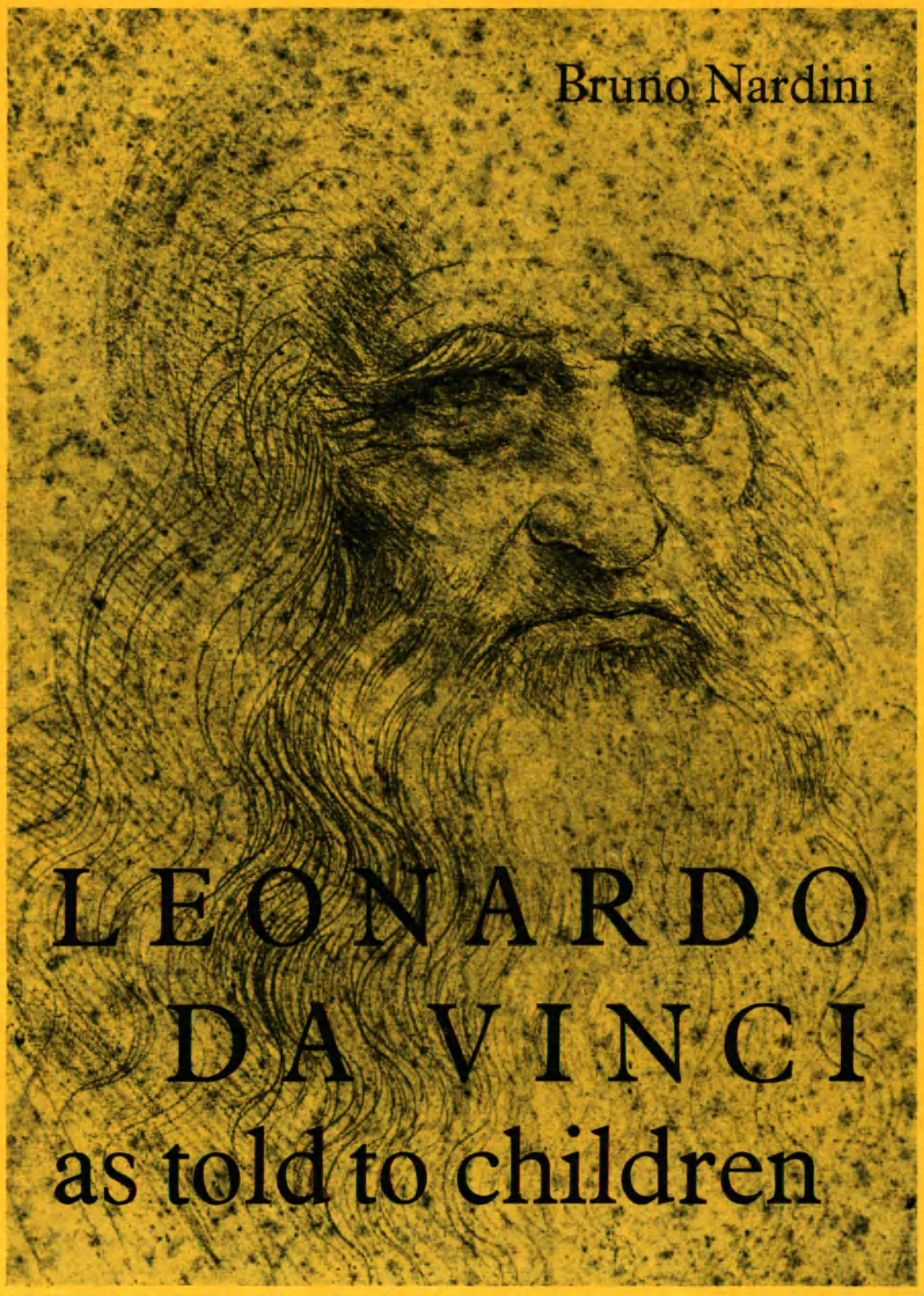


Bruno Nardini

LEONARDO DA VINCI

as told to children

Photo © Alinari-Giraudon, Paris.

Stretched out in the grass behind his grandfather's house a young lad, who was to grow up to be one of the greatest painters and sculptors the world has ever known, was watching the circling flight of a bird—a kite—round the main tower of the castle in the town of Vinci. His uncle was lying in the grass next to him, trying to explain the mechanics of the way a kite flies, soaring round in circles so as to exploit the slightest breath of a breeze. But the young lad was tired: his eyes were already closed and he had fallen asleep. His name was Leonardo da Vinci.

It was an afternoon in May, the earth was sweet with the scent of hay and crickets sang out from their hiding-place in the grass. Leonardo had a strange dream about the kite: he dreamt that he was still in his cradle, but no longer at home. Lucia, his grandmother, had carried the cradle into the field and then gone away.

The kite made ever-narrowing circles until it plunged from the sky and dropped on top of him; however, the bird did not scratch Leonardo with its claws or peck him with its beak. It simply flapped its wings and tried to open the boy's mouth with its forked tail. When Leonardo's mouth was opened in this way, the kite struck his lips and his tongue with its tail. Suddenly Leonardo woke up with a cry and found himself sitting on the grass with his uncle, Francesco.

"What's the matter with you?" asked his uncle.

"That kite", stammered the lad, still not quite sure that he had woken up from his dream, "Uncle, I had a dream about that kite!"

Many years later, when Leonardo was grown up, he wrote in the city of Milan that this was his first childhood memory, a striking one which he had never forgotten. Now that he was studying the mathematical laws that had to do with birds' flight, that kite seemed to him to have been some kind of messenger telling him his future destiny.

BRUNO NARDINI, *publisher and founder of the International Book Centre in Florence, is the author of "Vita di Leonardo" (Life of Leonardo), written for children and illustrated with stills from an Italian television film on Leonardo directed by Renato Castellani (Nardini and Giunti-Bemporad Marzocco Publishers, Florence, 1974). He has adapted the fables and legends which Leonardo jotted down in his notebooks into two books for young people: "Favole et Leggende", to be published in English as "Fables of Leonardo da Vinci" (Collins, U.K.; Hubbard Press, U.S.A.), and "Animali Fantastici" (Nardini and Giunti-Bemporad Marzocco, 1974). He has also published a book for youngsters on the life of Michelangelo.*

In this house, on the slopes of the Tuscan hills near Vinci, Leonardo was born on April 15th, 1452.

Photo © Maurizio Berlinconi, Florence

And what a splendid destiny it would be! Born in a poor village of Tuscany in central Italy, near the River Arno, he never had a mother of his own like other children, or a loving father. Instead he had a step-mother and a strict grandfather. His only real friend and teacher was his uncle Francesco, who was seventeen years older than Leonardo.

Leonardo was born on the 15th of April, 1452. The Middle Ages, a long period of gloomy tower-keeps and independent communes, were coming to an end. The period of local lordships, government by the richest and strongest, was coming in their place. The gloomy old keeps were giving way to luxurious palaces.

Leonardo arrived at Florence with his father, Ser Piero, on their horse-and-cart, for his father had decided to move to the big city for good, to work as a notary like his ancestors. Leonardo was also accompanied by Ser Piero's second wife, a young woman called Albiera who took the place of his mother.

We have no record of what happened during that first period of Leonardo's life at Florence. All we do know is that Ser Piero sent his son to do music and grammar classes; music consisted of learning to play the flute and grammar meant learning how to write. Then, in 1465, step-mother Albiera died and Ser Piero married again. Leonardo's new "mother" was called Francesca. By now he was thirteen years old and he had already decided what he was going to be when he grew up: not a notary, like his father, or his grandfather Antonio, but a painter.

It was quite by accident that Ser Piero found out his son's secret ambition. One day he went into Leonardo's room and came across a pile of neatly rolled up papers and realized that they were drawings. "Not bad at all", Leonardo's father said to himself. "In fact, they are pretty good."

Without wasting any further time Ser Piero put the rolls of paper under his arm and took himself off to show them to Andrea di Cione, whom we know as the painter Verrocchio. "Listen, Maestro," said Ser Piero, "I found these drawings done by my son. What do you think of them?"

Verrocchio looked at Leonardo's drawings one after the other, paying ever more careful attention, then he asked: "How old is this lad?"

"Just seventeen", was the answer.

"Then bring him round to me. He can live in my house. I'll turn him into a great painter."

The next day young Leonardo, accompanied by his father in a brusque,

Photo © Anderson-Giraudon, Paris

Sketch for the *Madonna with the Cat* executed during Leonardo's first Florentine period.

serious mood, entered Verrocchio's workshop as an apprentice. He did not feel out of place or nervous, and he didn't have to face his strict new teacher on his own. A crowd of young pupils welcomed him noisily among them: these were all young boys of his own age, and they too were to become famous in their own ways.

The oldest were Sandro Filipepi, also known as Botticelli, and Pietro Vannucci, known as Perugino. Amongst the younger pupils of Verrocchio were such names as Lorenzo di Credi, Francesco Botticini and Francesco di Simone. Surrounded by friends like these, in those enormous studios full of blocks of chalk and marble, with tables loaded with brushes and paints, Leonardo felt happy in the constant atmosphere of hard work and creation.

He willingly carried out the most humdrum tasks, sweeping the floor, washing the dishes, grinding the colour substances, preparing the paints, cleaning the brushes and posing for his master who was working on a statue of David.

But what occupied him more than anything else was keeping his eyes on everything that was going on around him, soaking in every experience so that he would soon know the tricks of the trade. A little later he was entrusted with the task of preparing the plaster for the frescoes; then he was allowed to transfer some of the "cartoons" (the word used to describe the plan the painter works from) on to the wall; finally he was given the brushes and told to touch up some of the work on the wall which Verrocchio had done himself.

One day Verrocchio had assigned Leonardo the job of painting an angel's head on a large canvas which represented "The Baptism of Christ". He noticed that the angel's head which he had already done on the painting wasn't so impressive as Leonardo's. The story goes that Verrocchio picked up his brushes and broke them, as if he was declaring that from then on he wouldn't have anything more to do with painting.

From this period in Leonardo's life come many sketches and studies of the horse; Verrocchio was working on

Florence, the city of towers, as it looked when Leonardo lived there until the age of 30 in 1482, when he left for Milan.

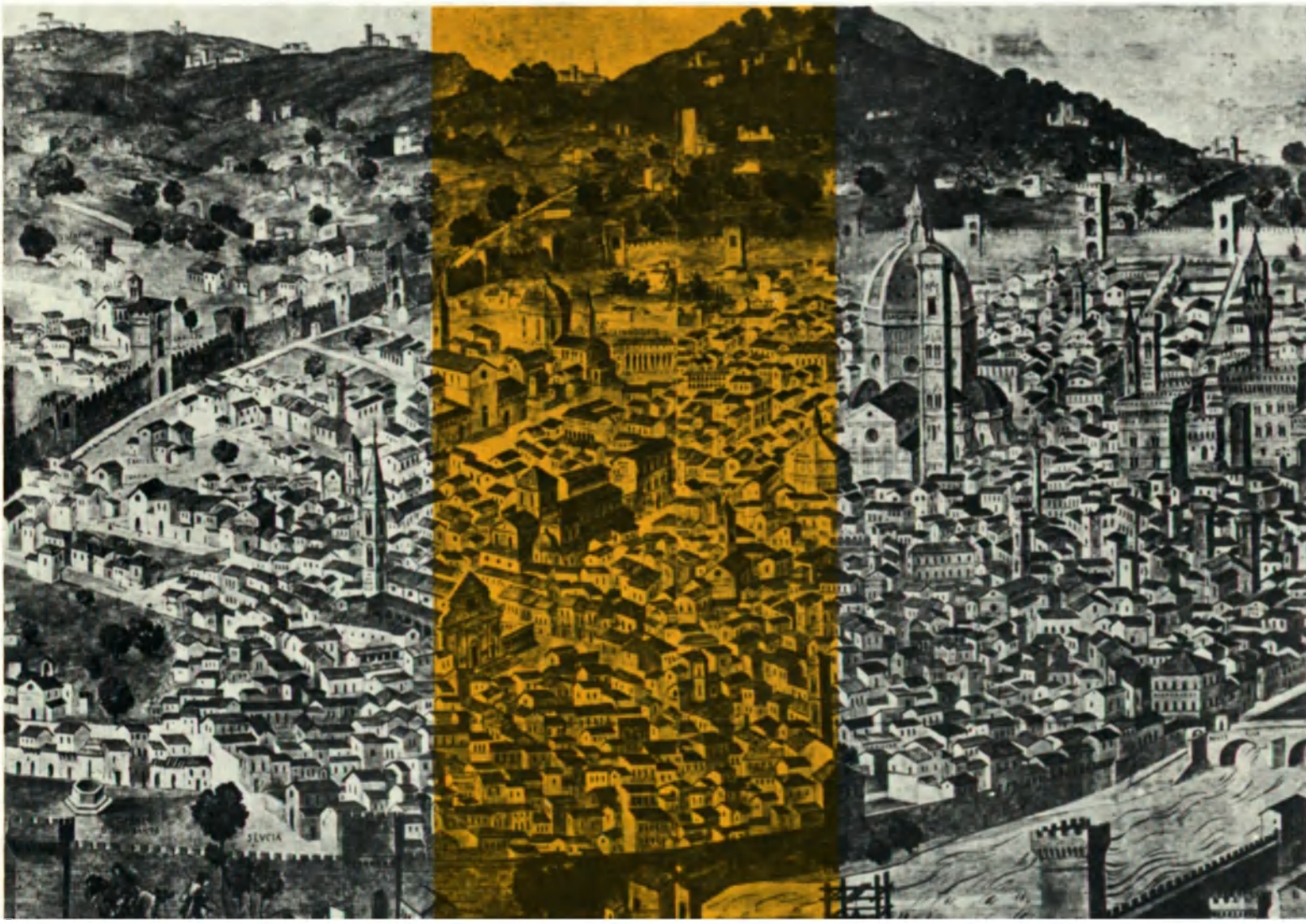


Photo © Scala Florence

Photo © Alinari-Giraudon, Paris

Leonardo's earliest work is a kneeling angel (detail below) which was his contribution to Verrocchio's *Baptism of Christ* (1473-78) shown at right. Leonardo painted it in Verrocchio's workshop where he was apprenticed at the age of 17.

Photo © Brogi-Giraudon, Paris

Head of Verrocchio's *David,* a bronze sculpture dating from about 1473, for which the young Leonardo, then aged 20, may have been the model.

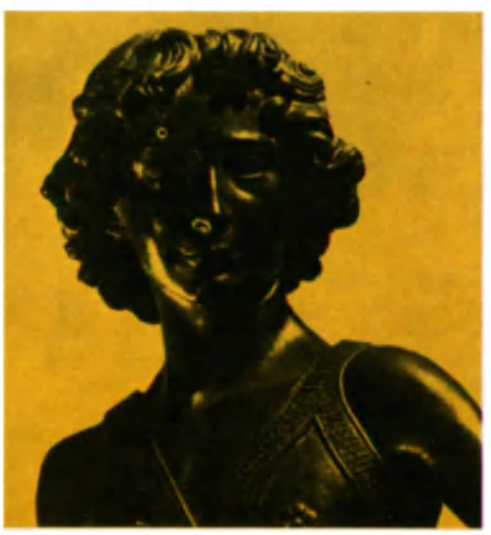


Photo taken from "Vita di Leonardo" by Bruno Nardini, Giunti-Nardini Publishers, Florence

a monument of Bartolomeo Colleoni, the military captain, seated on his steed. Leonardo often amazed his fellow-apprentices by drawing with his left hand, and he always wrote from right to left, back to front, like a wizard scribbling out his spells.

One day, when he was twenty-two years old, he decided to join the Guild of San Luca, an association of artists; so he left Verrocchio's workshop to set up in business on his own, as we would say nowadays. Lorenzo the Magnificent gave him a contract to draw a Madonna, another patron asked him for an "Annunciation", then he was asked for a Saint Jerome, and an "Adoration of the Magi".

His own father asked him to paint the wheel of a cart for a peasant from his home town of Vinci. He never refused anybody, he took all his jobs seriously, even the wheel, which he adapted into a kind of grotesque monster. With every task he undertook, Leonardo aimed to arrive at an even greater perfection, until eventually he had to give up and leave his works unfinished. This was the hidden drama of Leonardo's whole life.

Leonardo, however, was not just a painter. He also did sculpture. Earlier on he had modelled a number of human heads and a Via Crucis. Later on he was to sculpt an enormous horse. He was also a musician. He could play the flute and the lyre, and people who knew him have recorded that he "sang exquisitely".

At Vinci he had learnt from his uncle Francesco to distinguish the different plants and the effects they had: this means that he was also a skilled botanist and knew about herbs. At Florence he had come to know a number of famous doctors, and even started to study anatomy. At night he would slip into the hospital's mortuary to dissect the dead bodies and then sketch the various organs of the human body.

He studied the way rivers flow, and made plans for canals that ships could sail down. He read history books and books about the art of warfare, then he promptly sat down to invent strange new war engines. He studied buildings closely, among them the Cathedral of Florence where Verrocchio had placed an enormous ball of copper on the lantern (the open structure on top of the dome) designed by the great architect Brunelleschi, and he thought up extraordinary machines that could lift and transport huge weights in the air. He watched the way that birds fly and dreamt of a machine that would allow men to fly through the sky.

He analyzed the sea-bed and could already picture a frogman's suit and mask in his mind's eye. He watched men at work, and anticipated modern cybernetics and "time and motion" studies by working out machines that could cut out some of their movements and save them trouble.

He read the works of Greek and Latin philosophers, until he could discuss their ideas in such a way as to impress his listeners. He was not rich, but the generosity of those who appreciated his genius meant that he could live in the style of a prince. He was handsome, tall and strong: with his hands he was capable of bending a horseshoe. Yet he was also gentle and refined, full of help for others and never boastful.

He appreciated everything about life, and knew how to pick out the good side of things, the most noble and attractive ▶

The Adoration of the Magi, **a painting begun by Leonardo about 1481 but never completed (Uffizi Gallery, Florence).**

The Annunciation, **the first full painting completed by Leonardo (Uffizi Gallery, Florence).**

Photos © Anderson-Giraudon, Paris

Photo © Vatican Museum, Rome

This unfinished portrait of St. Jerome by Leonardo (about 1481) illustrates one of the great painter's theories: men and animals experience the same emotions.

side to life. He was a great lover of Nature: nowadays we would call him an "ecologist". He even planned an ideal city with lots of greenery and criss-crossed by canals, the streets carried overhead and the houses tucked underneath.

He also loved animals. Whenever he saw birds in a cage, he would buy them in order to let them go. He considered everything to be a "wonder of the universe", and whatever he set eyes on seemed to him to reveal the hand of its creator, God, whom he called "The Prime Mover".

Leonardo, then, was a man of the future, the first and most deeply convinced citizen of the world.

At the age of thirty Leonardo went to Milan, to the court of Lodovico il Moro, who had asked Lorenzo de Medici for a sculptor to carry out a monument in memory of his father Francesco Sforza.

There is an extraordinary letter which Leonardo sent to the Duke of Milan just after his arrival in the Lombard capital. In this letter he makes a list of all the things he knew how to do, like making giant slings and gun-shot for bombardment, self-propelling cannons, tanks, multiple machine-guns and siege platforms.

Photo © Royal Library, Windsor, U K.

From an early age Leonardo carried out meticulous studies of human anatomy. He made this drawing (about 1508) of the dissection of the principal organs of a woman.

At the end of the letter he even states that he can out-class all others at architecture, painting and sculpture, and challenges the Duke to put these abilities to the test.

Leonardo was taking quite a risk. Lodovico il Moro could have simply locked him up as a starry-eyed lunatic. Instead, the Duke summoned Leonardo to his presence, listened to what he had to say and gave him the task of raising the monument to his father. He also gave him the official title of "Engineer to the Duke."

It was at Milan that Leonardo revealed another of his secret passions: the art of staging elaborate shows, making him the equivalent of what we understand by the word "director". He produced an allegorical representation called "Paradise" for the marriage of Gian Galeazzo Sforza to Isabella of Aragon, as well as the "Joust" for Lodovico's wedding to Beatrice d'Este, and both performances have become legendary.

In the first show the seven planets were seen following their orbits round a star-studded sky, accompanied by music and singing, while the chariot of the sun, drawn along by steaming horses (an extraordinary example of self-propelling machinery), slowly crossed the stage. In the other show, the "Joust", a live horse covered with golden scales stole the scene, with a ram's head and a fitted tail that would have suited a serpent.

From this period which Leonardo spent at Milan there remain famous works like the painting *The Virgin of the Rocks*, of which a version by Leonardo's sole hand is in Paris, and a version by both Leonardo and the Milanese artist De Predis in a gallery

A charcoal, pencil and crayon portrait of Isabella d'Este, made at Mantua in 1500. (Louvre Museum).

Photos taken from "Vita di Leonardo" by Bruno

in London. He also did a "Madonna" for Matthew Corvino, the King of Hungary, and a portrait of a girl with a stoat in her arms, as well as a portrait of a woman in profile, who may well be Beatrice d'Este.

Lastly there is the stupendous *Cenacolo* (painting of Jesus' Last Supper), which has its own tragic story. What happened is this: Lodovico il Moro gave Leonardo the task of painting Christ's Last Supper with his Disciples .on to a wall of the dining-room in the Dominican convent

Lady with an Ermine, a portrait of Cecilia Gallerani, painted by Leonardo at the court of Lodovico il Moro, in Milan about 1483. (Museum Czartoryski, Cracow.)

One of Leonardo's secret passions was the staging of elaborate spectacles or shows on festive occasions. For the marriage of Gian Galeazzo Sforza to Isabelle of Aragon he put on an allegorical representation called "Paradise", in which a chariot of the sun crossed the stage drawn by a fuming, snorting horse, shown in photo below. The scene is taken from a seven-hour Italian television film, "La Vita di Leonardo", directed by Renato Castellani and to be screened in 120 countries.

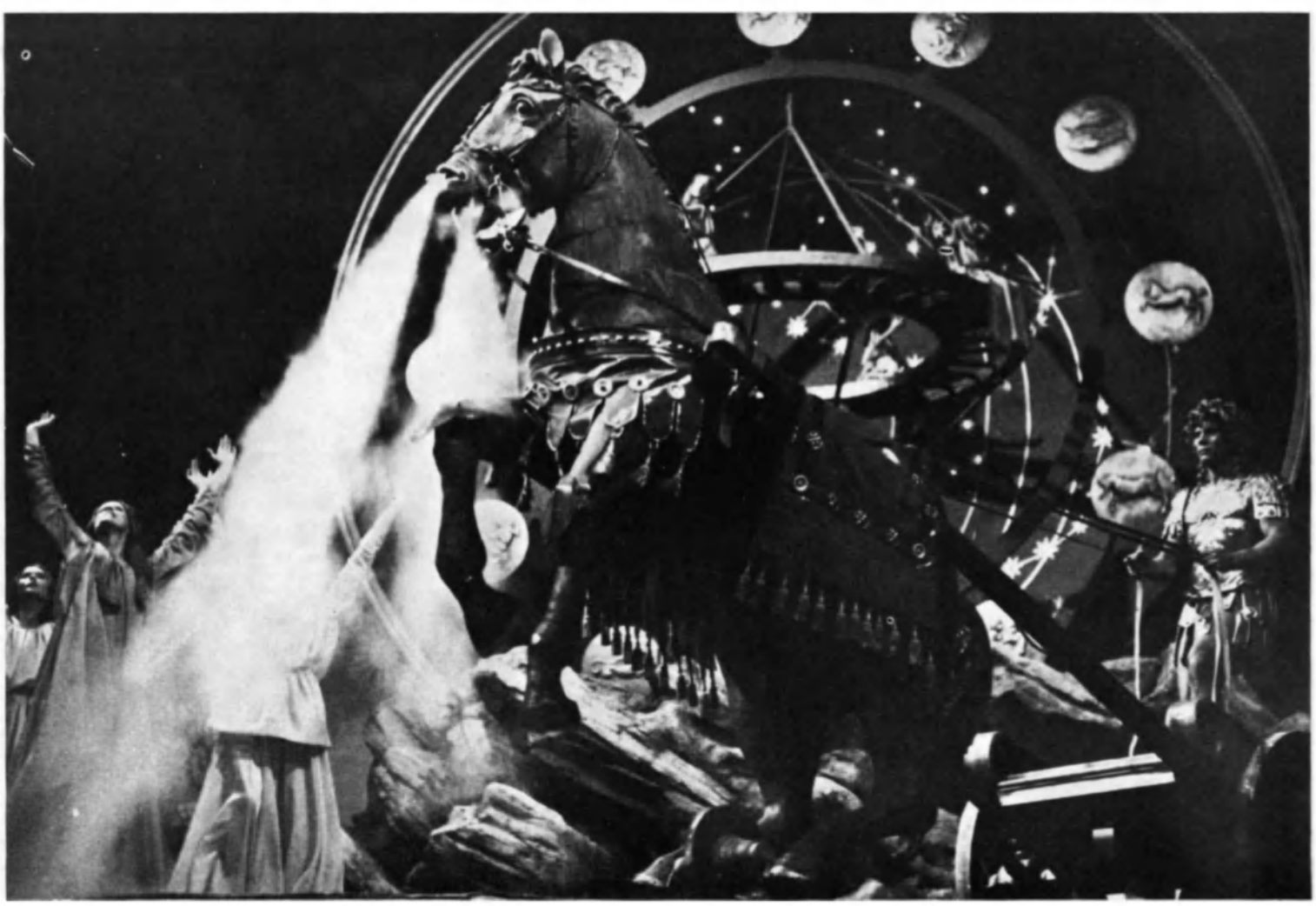


Photo from the film "La Vita di Leonardo"

UNESCO ARCHIVES

Leonardo contemplates the *Last Supper*, the monumental composition he executed in Milan, on a wall of the refectory of the Dominican Convent of Our Lady of the Graces in a scene from the Italian film on Leonardo. Around Leonardo are the sketches from which he worked to complete the painting. Below left, one of Leonardo's preliminary studies for the *Last Supper*.

Photo from the film "La Vita di Leonardo"

Photo © National Gallery, London

Photo Louvre Museum, Paris

Leonardo devoted two compositions to the theme of The Virgin and Child with Saint Anne. The first version, shown here, is known as the Burlington House Cartoon from the collection to which it formerly belonged. Most authorities date it from about 1498-99.

of Our Lady of the Graces (Santa Maria delle Grazie). Leonardo went straight to work: he even stopped passers-by in the street so as to fix some detail of movement or facial appearance in his mind's eye.

Night and day he worked on sketches and plans for the various characters in his mural, until the cartoon was ready in every detail. Unlike other artists, who had always tended to depict the Last Supper as a gloomy meeting before the final Passion, Leonardo's plan was to paint the exact moment when Christ uttered the words "One of you will betray me!" Horror, indignation and amazement were to be expressed on the faces of the Apostles, while Jesus would be seated motionless in the centre, isolated and detached from the passionate reaction of his followers.

But the ever-scientific Leonardo wanted to test out a new kind of plaster, made up out of three separate layers of stucco. When he had finished the painting, and the people of Milan crowded into the refectory to admire the completed masterpiece, Leonardo sadly realized that the layers of stucco were not capable of resisting the outside temperature to the same degree. This meant that his great painting would not last for very long. Fifty years later it was already wrecked, though we can still gain an idea of the original when we look at it today.

As soon as the painting was finished Leonardo had to leave Milan for Venice. The French troops of King Louis XII, under the command of Trivulzio, had entered Milan after the retreat of Lodo-

Photo © Royal Library, Turin

Study in silverpoint for the angel's head in the Louvre Museum version of *The Virgin of the Rocks* (see page 2). Deceptively simple in appearance, it is in fact one of Leonardo's most polished drawings, its subtle shading of slanted parallel lines creating an impression of depth and softness (from about 1483).

vico il Moro. A number of Gascon crossbowmen found an immense horse fashioned out of clay in a courtyard.

They had no way of knowing that it was Leonardo's model for the monument to Francesco Sforza, ready for its final casting into bronze. For that matter they would not even have known who Leonardo was. They played a game of knocking it to pieces, aiming at it with their crossbows to see who could hit it most often.

From Venice Leonardo moved back to Florence again, but this time he was returning to his city with a solid reputation built up over twenty years. He took lodgings with the Servants of Mary, in the Convent of SS. Annunziata, for he had promised them a painting of St. Anne and the Madonna for the main altar.

Everyone wanted something from him, every organization wanted his advice and recommendations. The Secretary of the Florentine Republic, Niccolò Machiavelli, even asked him if he could divert the waters of the river Arno, which flows into the sea at Pisa, in order to starve out the Pisans who were at war with Florence

Photo © Institut de France, Paris

Leonardo sketched this dredger resembling a twin-hulled catamaran. "This plough will be able to dislodge the mud from the bottom," he wrote, "and unload it upon the barge which is placed underneath it."

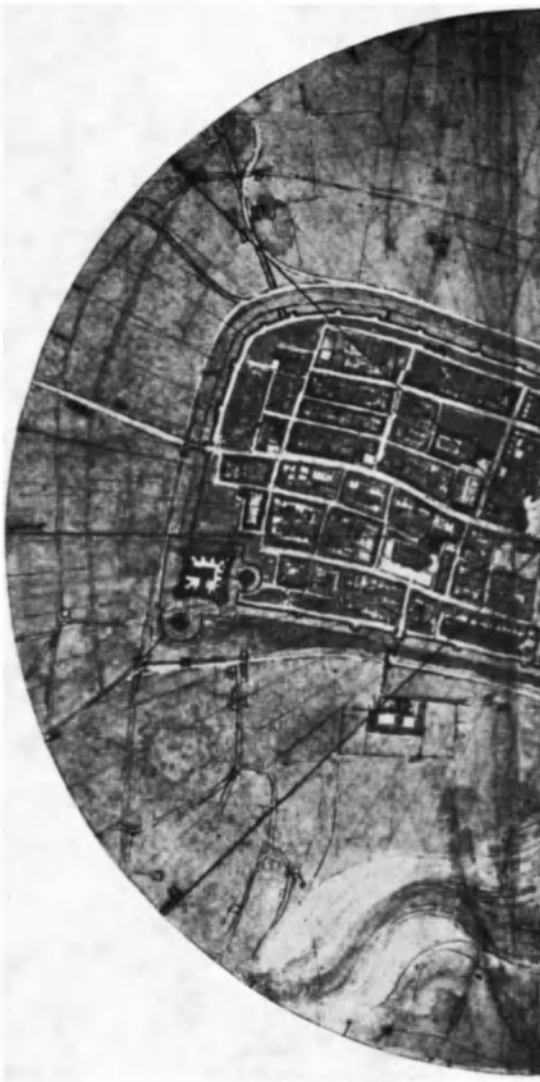


Photo © Ambrosian Library, Milan

Model of a car driven by springs, constructed from a drawing made by Leonardo da Vinci.

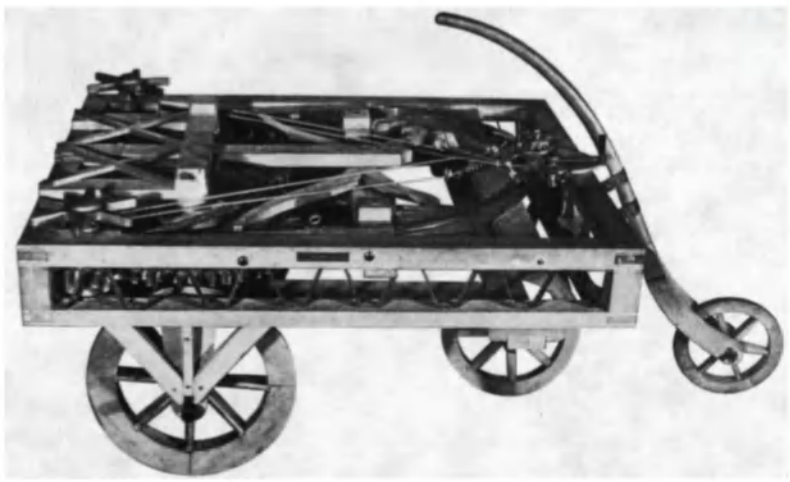


Photo © Mario Carrieri, Florence

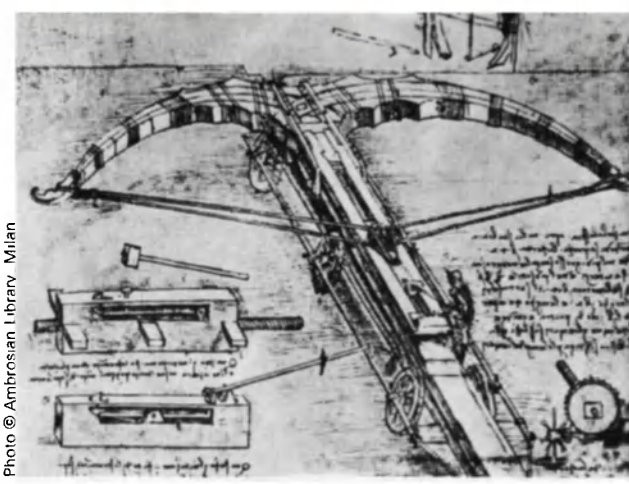


Photo © Ambrosian Library, Milan

Photo © Royal Library, Windsor, U K

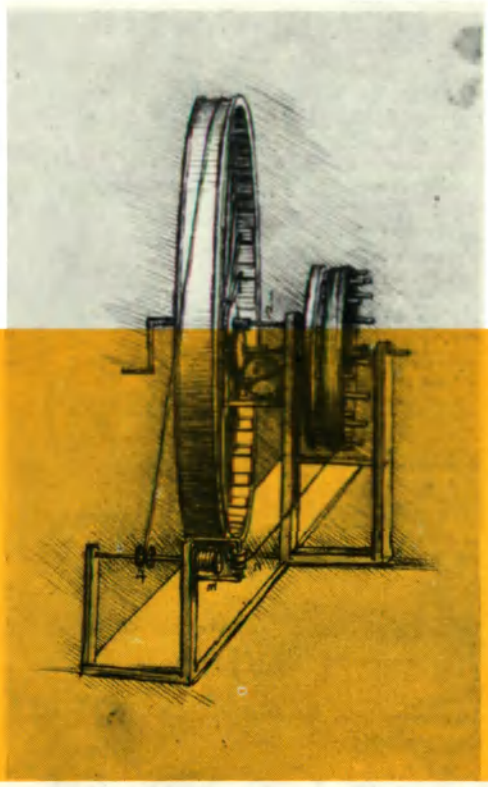
Leonardo was a skilled and ingenious cartographer far ahead of his time. He drew this plan of the town of Imola, near Bologna, in 1502.

at that time.

Leonardo never felt like refusing; his favourite motto was "I am never tired of serving others". But the friars of SS. Annunziata were impatient, so Leonardo locked himself in a room of the convent to work on the St. Anne and Madonna painting, and in less than a month the cartoon was ready.

For three whole days the people of Florence filed past Leonardo's design in a solemn procession. Amongst them was Pier Soderini, the ageing Chief Magistrate for life of the Florentine Republic, and also a young

Horse's head. Leonardo loved all animals and especially the horse to which he devoted many studies (see also pages 36-39).
Photo taken from "Vita di Leonardo" by Bruno Nardini, Giunti-Nardini Publishers, Florence



Drawing of a bombard for firing explosive shells, designed by Leonardo.

The discovery in Madrid of two lost manuscripts of Leonardo's (called Madrid Codex I and II) has revealed new aspects of his achievements as an inventor and engineer.
This meticulously drawn model of a spinning frame is from Madrid Codex I.

Drawing © 1974 by McGraw-Hill Book Co (U K) Limited, Maidenhead, England and Taurus Ediciones, S A, Madrid, Spain

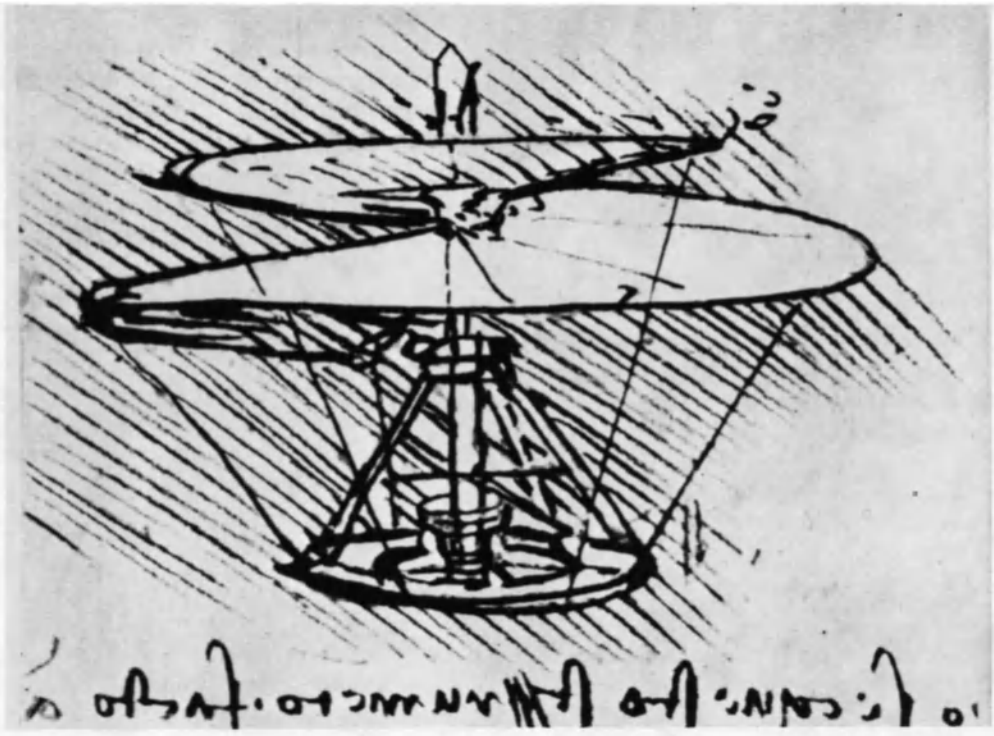
Leonardo's giant ballista, or catapult. The bow is built with laminated sections for greater flexibility and firepower. The inclined carriage wheels are a feature later incorporated in the wheels of artillery pieces.

Well over four centuries before the invention of the helicopter, Leonardo made a drawing of such a machine designed to lift off vertically from the ground. Here a 3-dimensional model built from his sketch.

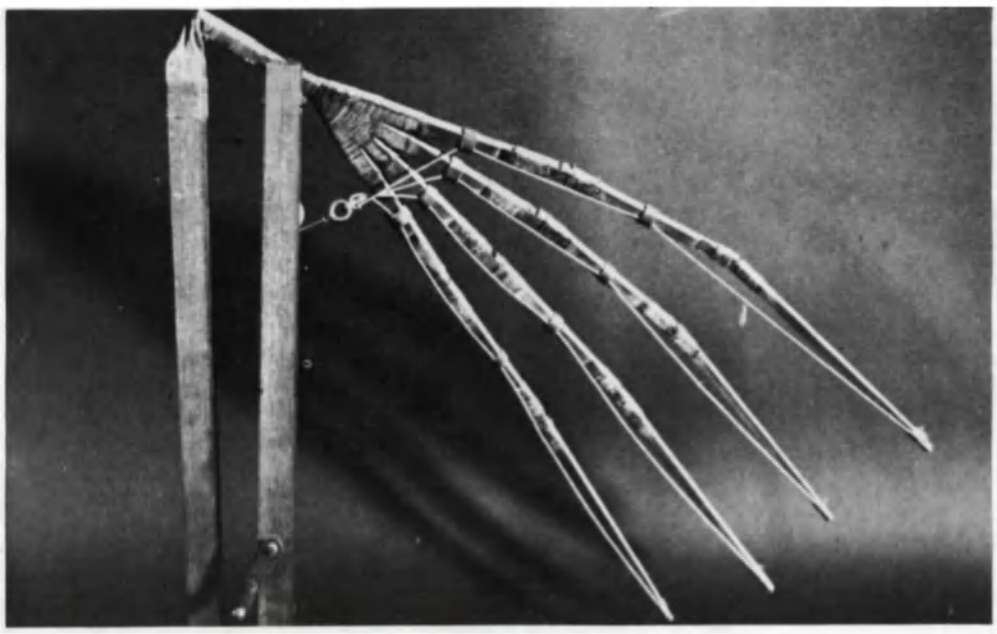
Photo © Science Museum, London.

Photo © Musée du Mans, Le Mans, France.

Photo © Institut de France, Paris

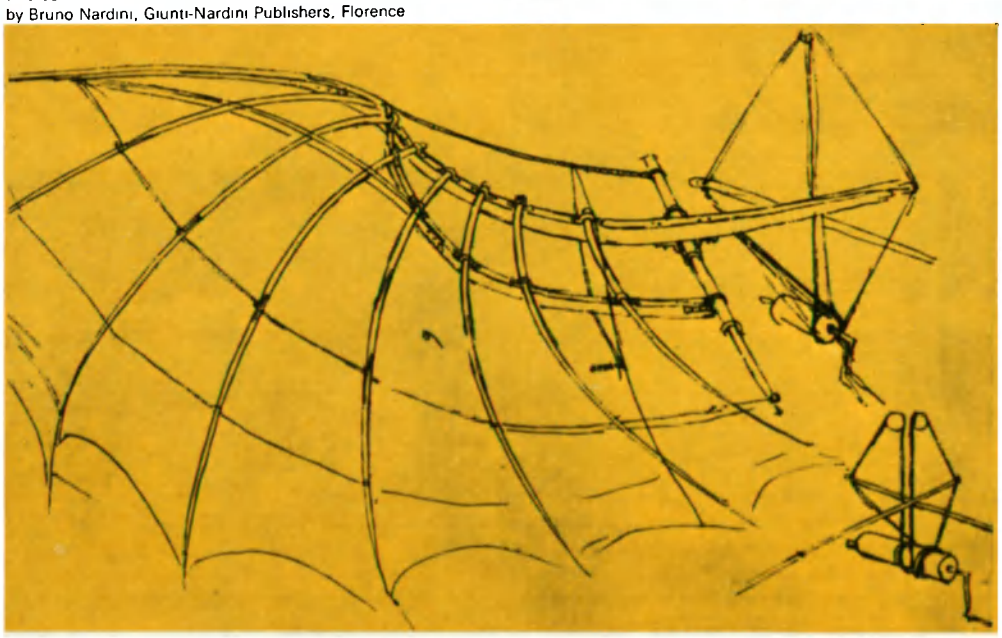


The earliest free-flying "whirlibird" dates from about 1320: pull a string and a spinning propeller will soar free. The one shown above is from a 1460 painting. Above right, Leonardo's design for a helicopter. Beside it he wrote: "If this instrument be well made... and be turned swiftly, the said screw will make its spiral in the air and will rise high."



Model of the articulation of a wing based on a drawing by Leonardo. His study of wings was astonishingly precise, particularly with respect to their curve, flexion and distention, and their rotation.

Photos taken from "Vita di Leonardo" by Bruno Nardini, Giunti-Nardini Publishers, Florence



Drawing of a ribbed wing by Leonardo with a crank device for manipulating it.

sculptor who had recently returned from Rome where he had completed a stupendous *Pietà*. His name was Michelangelo Buonarroti.

Writers of the time tell us that the rivalry that developed between Leonardo and Michelangelo was intense. It began when Soderini assigned Michelangelo a block of marble which had been lying behind the Cathedral for more than sixty years and had already caught Leonardo's interest. While Michelangelo was chiselling away at that marble to create his famous *David*, Leonardo had gone to Romagna with the rank of "Architect and general engineer" to its duke, Cesare Borgia.

When he got back to Florence he found that he had been chosen as one

LEONARDO AND FLIGHT

Leonardo was one of the great forerunners of modern aviation. On these pages we can see a few examples of his revolutionary ideas. One of his most cherished dreams was to enable men to "take to the air" by various means. After years of study he built a "flying machine", but its test-flight, like that of Icarus, was a failure, and Leonardo's hopes were dashed. Photo, the start of the ill-fated test, is from the Italian film on Leonardo.

Photo taken from the film "La Vità di Leonardo".

of the committee who were to decide what to do with Michelangelo's *David*. Michelangelo was irritated by Leonardo's presence on the committee, and they spoke rudely to each other.

When Soderini offered Leonardo a wall of the Great Council Hall of the Palazzo Vecchio to paint a battle scene, Michelangelo asked for the other wall to paint another battle scene on. This request was granted, and an elegant contest developed between the two great artists, which was watched and followed by the whole of Florence.

Both painters sought to excel themselves, rather than each other. Leonardo's cartoons, depicting the battle of Anghiari, and those of Michelangelo, dealing with an incident from the battle of Cascina, were shown to the general public at different times and places. The Italian artist and metalworker Benvenuto Cellini was later to call them "the school of the world."

In the meantine Leonardo was working on the portrait of a beautiful but rather melancholy woman, the celebrated "Gioconda", or "Mona Lisa."

After he had completed the cartoons for his battle scene, Leonardo began to paint his subject on to the wall of the Palazzo Vecchio. Yet once again the demon temptation of experiment led him astray. He had found in a work by the Latin writer Pliny a formula for a special plaster used by the ancient Romans called "encaustic". It was a kind of paste, based on a mixture of oily substances and Greek pitch, dried out against a flame to make the colours sharp and brilliant like enamel.

Leonardo made a series of successful tests, then decided to use the encaustic process for his Battle of Anghiari mural. But when his ambitious project was already nearing completion and only the upper half remained to be done, Leonardo discovered that the flame was too far away and the colours could not be hardened into place.

It was a desperately sad night for him: the colours were beginning to run, and Leonardo anxiously ordered more wood to be burned in the large brazier which was suspended by a pulley near the painting. But by now it was too late and the flame failed to harden the colours: by being brought too close to the wall it even spoiled the colours which had already dried. In the space of one hour Leonardo's planned masterpiece was ruined.

With an icy feeling in his heart Leonardo fled to a friend's house in the nearby village of Fiesole. But here he was destined to meet with another failure. After years of study he had finally rigged up a mysterious "flying machine". Everything was ready for an imposing test run, and this took place on Mount Ceceri (which means "swan"). But the human swan (an assistant of Leonardo's) could not get up into the air with the machine and stay there. He managed to cover a few metres and then plunged into the bushes underneath him. Thus another long-cherished dream was shattered.

By now he was happy to leave Florence, and went back up to Milan. The King of France, Louis XII, wanted him in his court, and the Governor of Milan, Charles of Amboise, heaped him with honours and favours. Leonardo recovered his nerves again, started enjoying his friends' company, and went back to his scientific research. He painted a series of Madonnas for the King, which are now unfortunately lost.

But political upheavals made it necessary for Leonardo to leave Milan. Lodovico's son was returning to recapture Milan, and the venture was

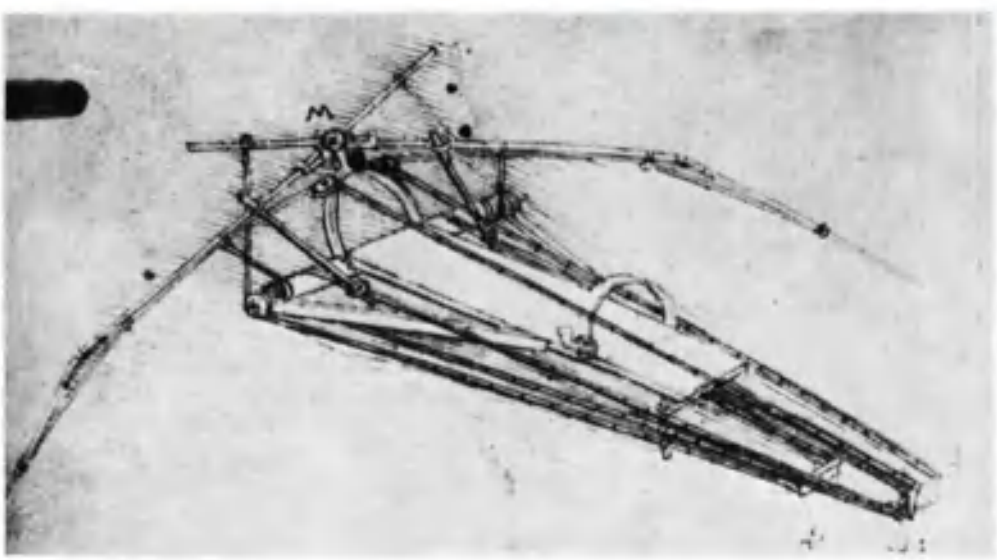


Photo © Institut de France, Paris

One of Leonardo's earliest aircraft designs (1486-90). The aviator lies on the board with his head through the front hoop. The wings, pivoting above the head at "m", are raised by the left foot and lowered by the right.

backed by troops of Swiss cavalry. The French thought it best to retreat back over the Alps, and Leonardo took refuge in Vaprio d'Adda, at the home of his young pupil Francesco Melzi.

Meanwhile Pope Julius II had died at Rome, and Cardinal Giovanni de Medici, son of Lorenzo the Magnificent, had been elected Pope with the title Leo X. Gradually the artists began to flock to Rome from all over Italy, and Leonardo decided to go too. Giuliano de' Medici, the youngest of Lorenzo's sons, put him up as a guest in his palace and gave him various commissions: a portrait of a woman, research into optical mirrors, and a project to reclaim the Pontine marshes.

France, however, was planning to recapture Lombardy, which now had an alliance with the Pope. Louis XII was dead, and his successor, the youthful Francis I, made a quick move across the Alps and defeated the defending Italian force at Marignano. Leonardo had left Rome with the court of Giuliano de' Medici, who was commander in chief of the Pope's army. But Giuliano fell sick and stopped at Florence, where he died.

Leonardo continued with the army as far as Piacenza. The Pope then came up to Bologna, in an attempt to counter-balance the military defeat by a diplomatic conference with the French monarch. Because he knew that Francis I was a great art-lover, the Pope called for a number of artists, including Leonardo, to be present at the conference.

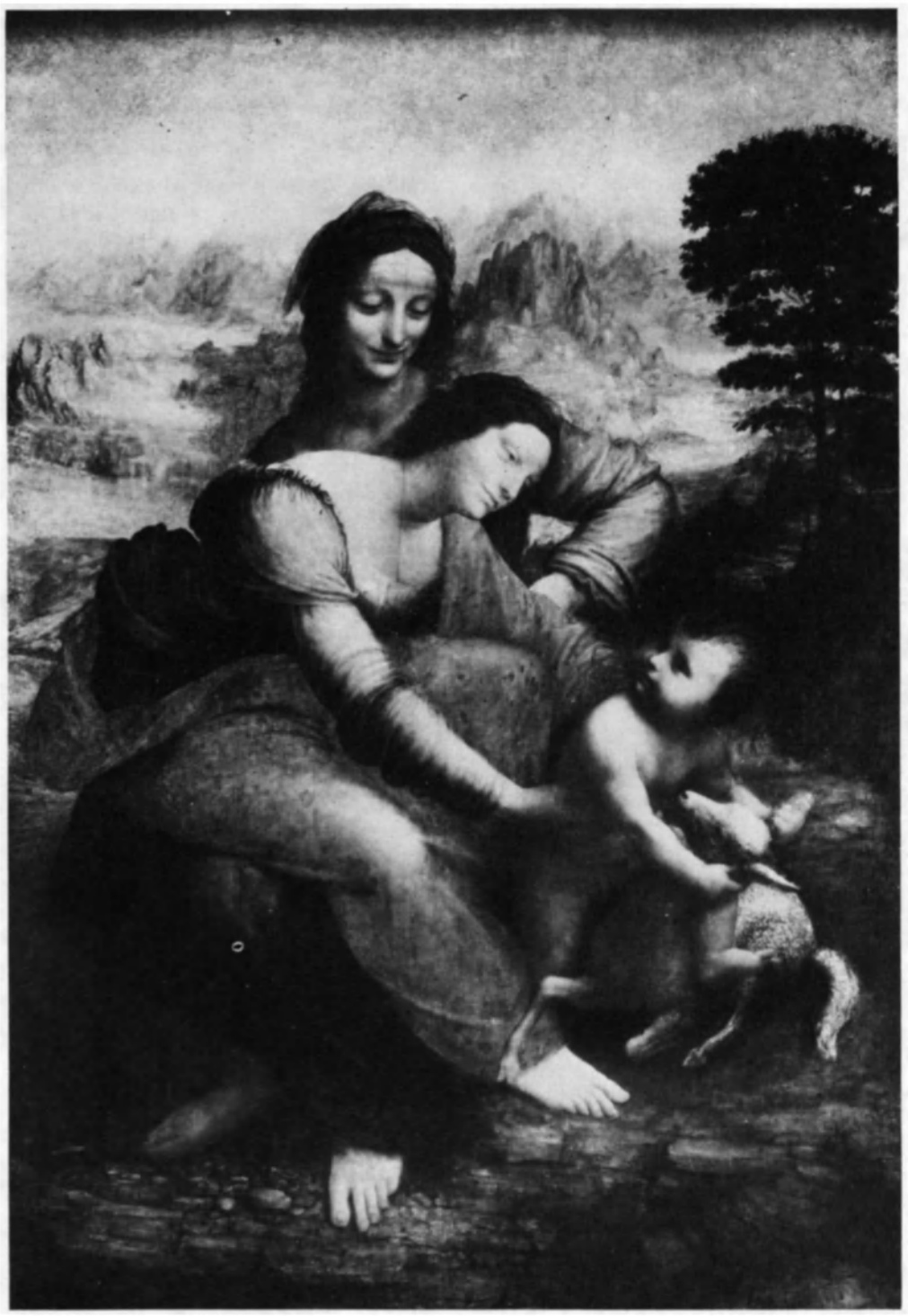
When Leonardo was presented to the French king he was as amazed as everybody else when the king came up and embraced him with the words "My father...!"

Two days later Leonardo accepted the king's invitation to go to Amboise in France, where His Majesty would make a whole castle, Clos-Lucé, personally available to him.

Now begins the long slow twilight of Leonardo's life. Helped by his faithful pupil Francesco Melzi, the ageing artist began to reorganize his writings and drawings in order to collect all his research into a "corpus", or grand encyclopaedia containing ancient, medieval and contemporary knowledge.

The French king never asked for specific paintings from Leonardo, he was content just to go and see him and hear what he had to say about things. Later on Cellini would say: "I heard the king declare that he did not believe there could be a single man in the world who knew as much as Leonardo... and that Leonardo was a supreme philosopher."

As a favour to the king, Leonardo drew up an astonishing project for a canal system in the Loire. He planned a castle for the king's residence and organized an enormous festival marked by the appearance on stage of a roaring lion which hears the king's name and then tears its breast with its talons, causing a cascade of French lilies to come out of it.



Photos © Giraudon, Paris

The second version of Leonardo's painting of the Virgin and Child with Saint Anne (Louvre Museum) dating from between 1500 and 1510 (the first version appears on page 27). In the two compositions, Leonardo used entirely different techniques and styles. Can you spot the eagle that Leonardo included, perhaps unwittingly, in the drapery of the leaning figure of the Virgin?

The Mona Lisa is undoubtedly the most famous painting in the world. Painted by Leonardo in the early years of the 16th century, it now hangs in the Louvre, in Paris. Mona Lisa has recently been on a world tour, attracting long queues of people willing to wait for hours to catch a few seconds' glimpse of her enigmatic smile.

In his death agony, on May 2, 1519, Leonardo imagined that King Francis I of France had entered his bedroom, at Amboise. This legend has been immortalized in this famous drawing by the French painter Ingres.

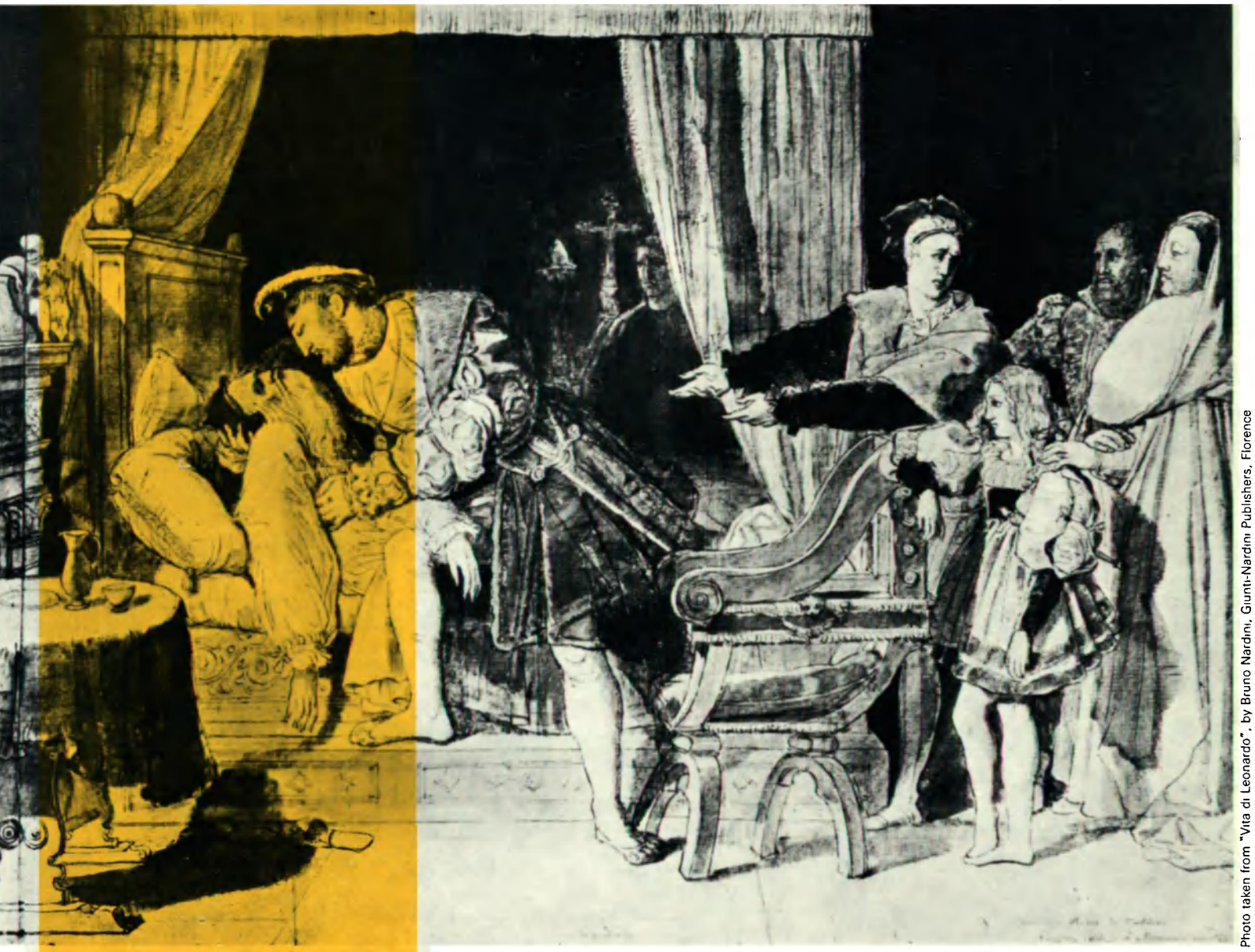


Photo taken from "Vita di Leonardo", by Bruno Nardini, Giunti-Nardini Publishers, Florence

In the peaceful surroundings of Amboise Leonardo relived in solitude his long life of toil, and wrote in his diary: "A well spent life is a long one."

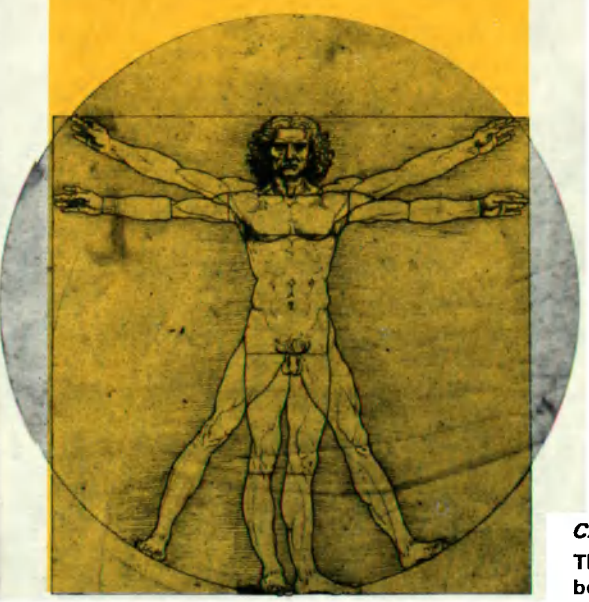
A kite flew above the castle of Amboise. It was spring, May 2nd in the year 1519. In his ill-lit room Leonardo was dying. He had a vision of the king hurrying to be with him, already arriving down below in the courtyard, and yet nobody came to his side. He wanted to call out aloud, but his voice would not obey him.

Finally a rough, indistinct sound emerged from his lips. His pupil Melzi heard him, and rushed in to lift Leonardo onto the pillows and arrange round the dying man's shoulders the fine cloak which he always wore when Francis I came to visit him. In his feverish delirium Leonardo then imagined that the king was coming into the room, approaching his bedside and embracing him in tears.

Leonardo was overcome by his emotion and closed his eyes.

This legend, for that is all we can call it, has been immortalized in a famous drawing by Ingres. But if Leonardo did not die in the arms of the King, it was only because Francis I was far away from Amboise at the time. Otherwise he would have rushed like a son to Leonardo's bedside, and the legend would have been made into reality.

Bruno Nardini



CANON OF PROPORTIONS

The ideal proportions of the human body as Leonardo saw them.

Photo © Anderson-Giraudon, Paris

Continued from page 18

look strange. The one on the left has two broad slits on the side of the tube, and the other has one long, thin slit.

Fortunately we have an explanatory text in Leonardo's most beautiful calligraphy, running from right to left: "These two flutes do not change their tone by leaps as most wind instruments do, but in the manner of the human voice; and one does it by moving the hand up and down just as with the coiled trumpet and more so in the pipe *a;* and you can obtain one eighth or sixteenth of the tone and just as much as you want."

Obtaining an eighth or a sixteenth obviously means—in acoustical language—to reach the upper octaves; and "moving the hand up and down" evidently means not to stop prearranged finger holes, but to move along the slits to change pitch gradually, or as we say today, to produce glissandos, or gliding tones.

Where could he have found the idea or a model for his glissando pipes? The clue lies in the words "the human voice", though I must confess that I found the solution by chance and then had it confirmed by Leonardo's own words. The model for our glissando pipes is found in the larynx, and it is significant that Leonardo calls the larynx "the human voice", applying this term to the machinery that produces the voice as well.

Leonardo made designs of the larynx and the trachea, now in Windsor Castle, in which we recognize immediately that the upper opening resembles that of a recorder. Furthermore, in accompanying texts in the anatomy manuscripts the trachea is called *fistola*, which is also the name of a vertical flute such as the recorder.

There is, though, one flaw in our analogy: Leonardo wrongly attributed the change of pitch of the human voice to the narrowing or widening of the cartilage rings of the trachea and failed to observe the function of the vocal cords in the larynx. This failure was probably caused by the technical difficulty of dissecting the small and fragile larynx. (By the way, Leonardo's drawings are thought to have been based on the anatomy of an ox.)

Still, we have in Leonardo's glissando recorder a new musical instrument which opened, or could have opened, a new musical horizon; which works well (some reconstructions that I have made function perfectly); and which was patterned after an anatomical analogy, that of the larynx, even though Leonardo misunderstood its actual function. Hence we have here a positive result built upon wrong premises.

The Madrid Codices contain only a few pages devoted to musical matters, but they add considerably to our knowledge of Leonardo's interest in music and musical instruments and to our comprehension of his indefatigable mind, so overwhelmed by new ideas, associations, and technological imagination that he could cope with this onslaught only by jotting down passing thoughts, often so sketchily that important details, which he evidently took for granted, are neither delineated nor explained in his comments.

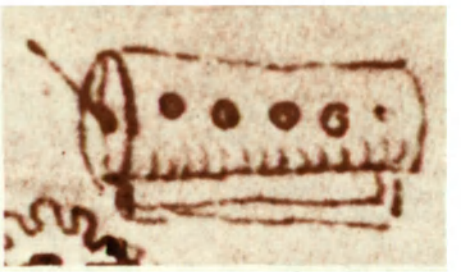
In drawing, above from Codex Arundel, **Leonardo has combined three drums into a single instrument. It consists of three shallow boxes beaten by mechanism attached to left of drum, and was intended to produce a chord of three tones. Models have been made of most types of drum sketched by Leonardo and they have been found to work well.**

One of Leonardo's drawings of musical instruments in the Madrid Codices is of a bell with a wide rim. Instead of a clapper inside, two hammers strike the rim from opposite sides. To the left of the bell there is a mechanism including what seems to be a set of four keys operating on a tracker action that in its turn controls four levers ending in oval heads. In my opinion, these heads must be dampers. The accompanying text says, "The same bell will appear to be four bells. Organ keys with a fixed bell. And when struck by two hammers, there will be a change of tones as in an organ."

Acoustically important in this explanation are the indication that the bell is firm, neither swinging nor equipped with a clapper in the manner of a church bell, and the statement that it produces "a change of tones", which is in all probability one of pitch, not of timbre.

Thus Leonardo must have believed that the upper section of the bell has ring-shaped areas that produce tones of different pitch if they are slightly muted when the rim is set into vibration by the hammers. It is interesting that Leonardo, here as in many other of his musical inventions, tried to obtain from one instrument what could normally be produced only by several instruments or by an entire set of instruments. ■

Emanuel Winternitz



Another of Leonardo's brilliant solutions to the problem of obtaining different tones from a single drum is shown in sketch above from Codex Arundel. **This drum has holes in its sides like a flute. It has been reconstructed by the author of this article, who found that by closing the various holes while beating the drum he could in fact obtain differences in pitch.**

Drawings from Codex Arundel
© British Museum, London

Drum shown below, one of the series Leonardo drew in Codex Arundel, **is another attempt to combine several drums into one. It was almost certainly intended to produce a chord. Unfortunately, Leonardo's drawing does not allow us to understand the connexion between the body of the drum and the curious cones inserted into it.**

Continued from page 14

devices, mechanisms using the spring principle to obtain a constant motor drive, cog-wheels to transmit motion, and so on. Leonardo pays considerable attention to the problem of reducing friction and comes up with some ingenious solutions.

Here I should like to develop several observations by Carlo Zammattio, who has pointed out how absorbed Leonardo was in water-courses when he was in Lombardy. Leonardo was interested in water and the uses it could be put to, such as providing power for machines, driving a mill-wheel, etc.

A particularly compelling example of the way Leonardo proceeds to a universal rule from his observation of a specific phenomenon is provided by his method of working out the "powers" (i.e. the motor force) of a series of jets of water pouring from apertures of the same size but at various different heights in a receptacle which is kept full of water at the same level. Now, Leonardo is aware that the force behind the individual jets remains identical.

This is how he explains the phenomenon: each particle of water, once it falls free from the aperture, responds exclusively to its own weight and acquires an impetus which produces a corresponding force of impact if it meets something in its path. But in the original receptacle, the water particles are subject not only to their own weight, but also to the weight of all the water that lies above them.

So when the jets of water emerge from their apertures at varying heights and fall towards the same horizontal surface below them, the force of their impact is bound to remain constant, because their "power" is a sum of the weight of the column of water that pressed down on them in the receptacle and the velocity acquired during their downward trajectory once released from it. Hence the more the one increases, the less the other becomes, and vice versa.

Zammattio points out that the method and conclusions in this analysis by Leonardo correspond to the theorem enunciated in 1738 by Daniel Bernoulli, in other words, the fundamental equation of hydrodynamics. Such were the formidable results which Leonardo was capable of drawing from minute observation.

A number of other comments remain to be made in connexion with Leonardo's *Madrid II Codex*. There is, for example, a passage which immediately became famous because of its obvious reference to Leonardo's mural for the Palazzo Vecchio in Florence, *The Battle of Anghiari*, which was ruined before completion:

"Friday the 6th of June, 1505, at the stroke of the thirteenth hour I began to paint in the Palace. As I lowered the brush, the weather changed for the worse and the bell started to toll, calling the men to the court. The cartoon was torn, water poured down and the vessel of water that was being carried broke. Suddenly the weather became even worse and it rained very heavily till nightfall. And the day turned to night."

Some persons have considered this passage as a solemn record of the day on which Leonardo began to paint *The Battle of Anghiari;* this interpretation does not seem to me to have a solid basis. This is a typical reference to an exceptional meteorological occurrence. These always fascinated Leonardo, and as well as arousing his scientific curiosity about their natural causes, stimulated the fantastic, apocalyptic side of his imagination.

A long list of Leonardo's books comes next, containing 116 titles. It is the longest list of book holdings that Leonardo has recorded in any of his manuscripts, and therefore constitutes a precious source of information about the authors which he drew on.

There is also a shorter and more cursory list of fifty books. The titles are not recorded and the books are simply grouped according to their shape and size. This list almost certainly refers to autograph manuscripts by Leonardo himself.

There are also some superb coloured maps of the Arno valley and the plain of Pisa, drawn up as part of Leonardo's research into a plan to divert the course of the Arno in order to cut Pisa off from the sea at a time when the Pisans were at war with Florence. These maps can be dated to the summer of 1503. Also there are the red chalk sketches of mountains which we have already referred to.

A side of Leonardo's activities which was completely unknown until the discovery of the *Madrid II Codex* is revealed in the repeated references around November and December 1504 to Leonardo's work on the harbour and citadel of Piombino. The Codex contains many drawings dealing with problems of architecture and fortifications.

Once again the insatiable student of nature that Leonardo was could not resist the proximity of the sea, and in the Madrid II manuscript we find notes on currents, winds and navigation. There are also drawings of sailing ships in the different positions they adopt according to the changing direction of the wind. Often these drawings are no more than a few rapid strokes but they are always strikingly evocative.

Then come drawings and notes on the flight of birds, descriptions dealing with aspects of painting, comments on geometry, proportion, and so on. The quantity of material is breathtaking.

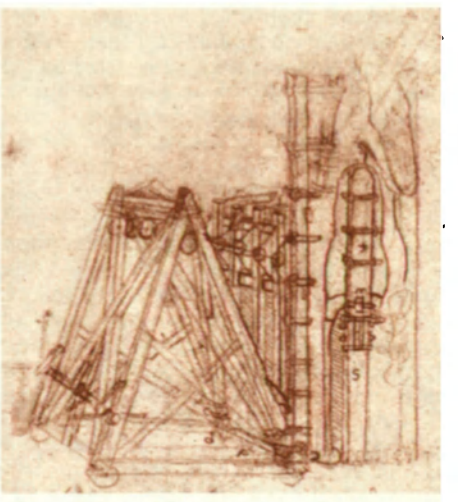
However, *Codex Madrid II* is not a single manuscript. It actually contains two separate manuscripts. The folios numbered 141 to 157 verso make up a separate section entirely devoted to the casting of the "Great Horse of Milan" for the monument to Francesco Sforza. This monument was never cast. Leonardo protracted his research into it for so long that the duke eventually used the bronze which he had allocated for the horse to smelt some cannons instead. Nonetheless, the detailed studies which Leonardo made for the project and which he records in these pages are packed with bold and ingenious solutions.

Taken together, the two Madrid Codices cover a long period of time, from 1491, a date which can be found in the part devoted to the casting of the Great Horse, to 1505, the date of the projected Battle of Anghiari mural. This period stands at the very centre of Leonardo's creative span, covering his experience at Milan and Florence, his activities as "engineer general" to Cesare Borgia, and (as we now know from *Codex Madrid II)* his service as an engineer to other local despots, such as the Duke of Piombino.

Above all, the Madrid notebooks were rediscovered at a time when Leonardo studies were directed more at the contents of da Vinci's manuscripts than his paintings and other works of art proper. The immense range of subject matter found in the notebooks, especially the scientific and engineering studies, has come to light at a time when the world is increasingly interested in science and technology and their history.

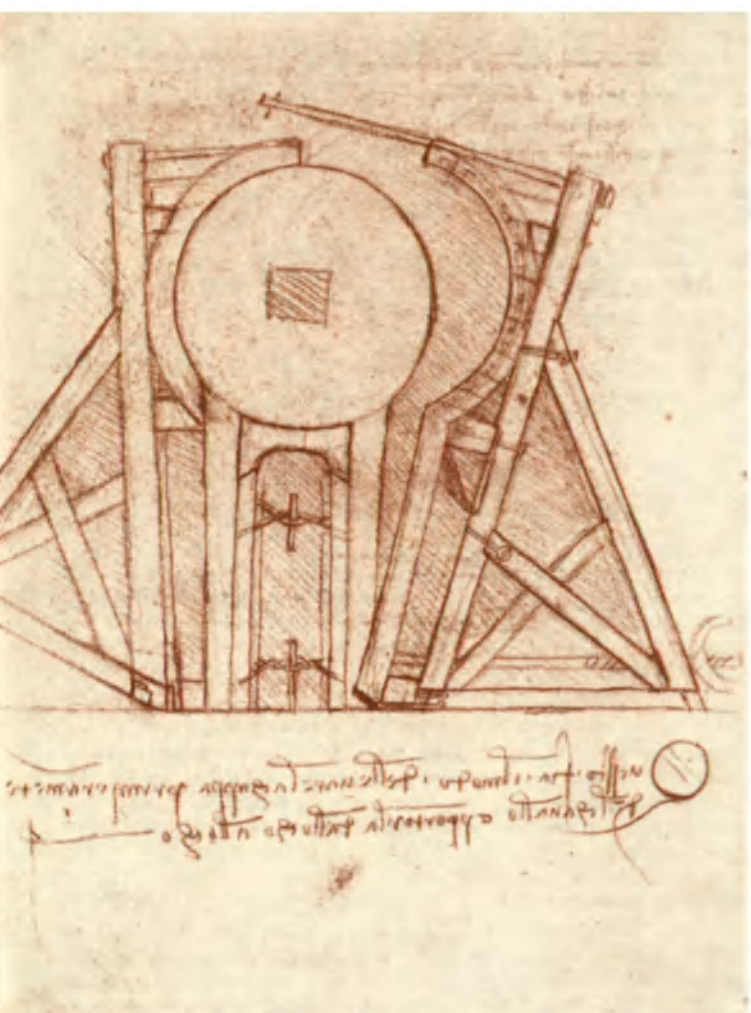
The forthcoming publication of the facsimile edition of the Madrid Codices, reproducing the beauty and elegance of the originals, will place a unique fund of new knowledge at the disposal of scholars and the general public everywhere. ■

Anna Maria Brizio



The three drawings shown on these pages reveal in what detail Leonardo studied the problems of casting his colossal bronze statue. Never before had such a great statue been cast in a single operation. On manuscript sheet from Codex Madrid II **(opposite page, top) Leonardo sketched the horse, jotted down the date, December 20, 1493, and wrote : "I have decided to cast the horse without tail and lying on the side." (In fact he later changed his mind and decided to cast it upside down to allow proper distribution of the molten bronze. See illustration page 38.) Above, sketch from** Codex Madrid II **of structure for transporting the huge mould and placing it in position in the ground. Opposite,** Madrid II **sketch showing now the mould would be opened.**

The story of the **colossal** horse



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IN 1482 Leonardo wrote a remarkable letter to the ruler of Milan, Lodovico Sforza. In it, the brilliant and self-confident young man of thirty offered his services as engineer and architect, and at the end of the letter, in a cunning attempt to arouse Lodovico's interest, he suggested that "the bronze horse may be taken in hand, which is to be to the immortal glory of the prince your father of happy memory..."

He was referring to the equestrian statue which Lodovico wanted to construct of his father Francesco Sforza.

Leonardo was hired as an engineer by Lodovico and during the next ten years or so he pondered and planned how to construct this great monument, in the intervals between amusing the court with entertainments and painting *The Last Supper*.

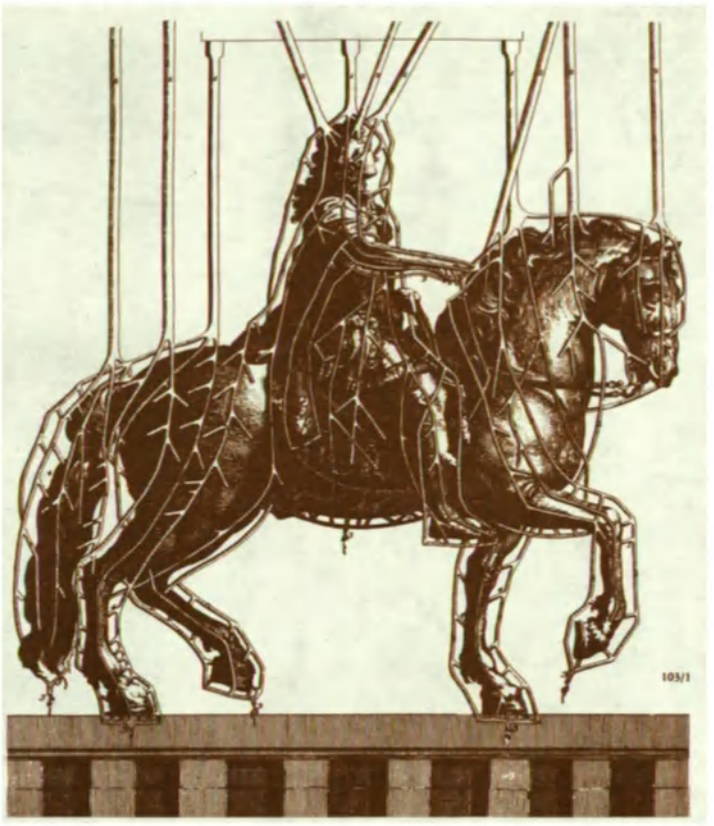
Originally the bronze statue was to be life-size, but as Lodovico's power and ambitions mounted, so did the size of the monument. Finally the horse alone was to be over 23 feet high. To cast it, 100 tons of bronze would be required. No sculpture of this size had ever been attempted before.

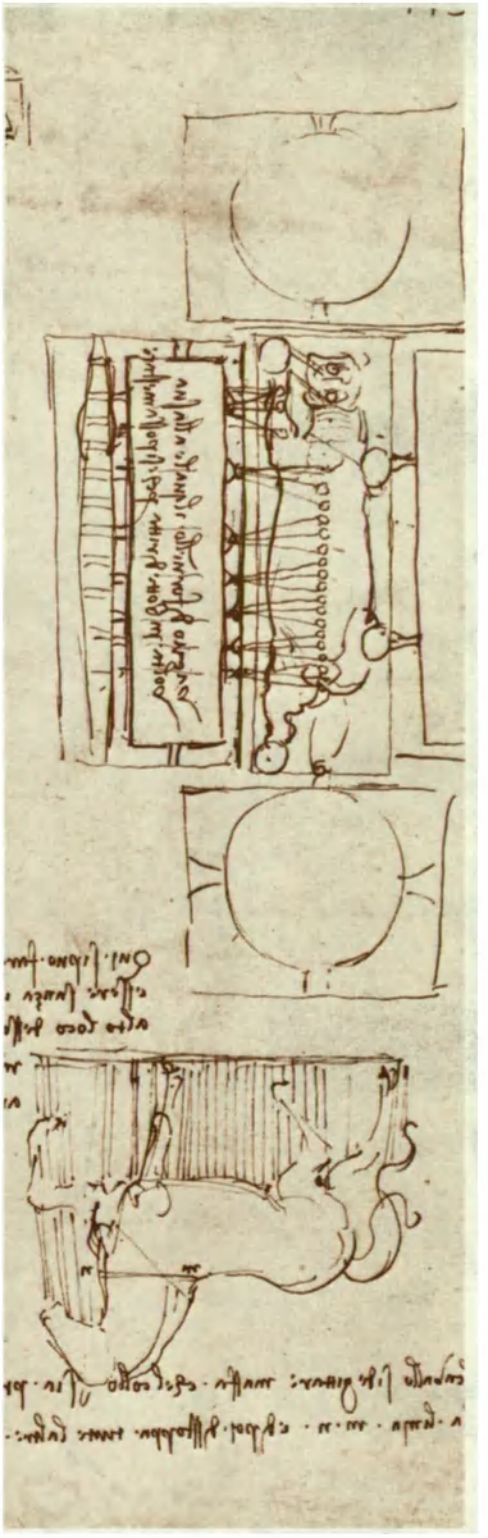
Leonardo wanted to cast the colossal statue in a single operation to avoid the disfiguring seams which mar statues cast in several pieces. But existing technology was inadequate for a single casting on such a scale.

By May 1491 Leonardo had completed a full-scale clay model of the great horse. It was unveiled in the old yard of Lodovico's ducal residence at a betrothal ceremony in November 1493, and became one of the wonders of Milan. But the horse was never cast. In 1494 the bronze set aside for it was sent to Lodovico's brother-in-law to be made into cannon.

For centuries no one could be sure whether Leonardo had solved the intractable problems of casting on such a massive scale. Now the problem is clarified by almost twenty fascinating pages in the second Madrid notebook in which we can actually see Leonardo thinking aloud about the casting. These notes are virtually a treatise on casting problems.

Leonardo draws the horse's pose. He sketches the ▶





Drawings taken from "The Unknown Leonardo"
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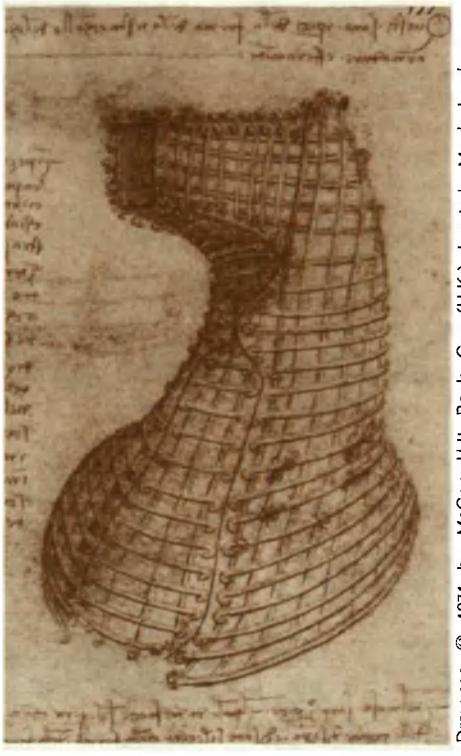
Photos above and right reveal the remarkable similarities between the casting method Leonardo invented and that used two centuries later in the making of the statue of Louis XIV (above) with its network of tubes into which the bronze was poured. Right, a page of Codex Madrid II **on which Leonardo visualized the casting pit for his horse, with, above centre, an 18th-century schematic drawing (from above) of the casting pit of the Louis XIV statue. The resemblance between the two pits is unmistakable. Sketch at bottom of manuscript page (right) was made by Leonardo after he had decided to cast the horse upside down. (See illustration on previous page.)**

Outer mould of the great horse from Codex Madrid II **shown on front cover.**



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mould. It "can be made in one day", he notes. "Half a boatload of plaster will serve you. Good." He decides to cast the horse on its side. Then he changes his mind and thinks that it would be better upside down. He draws the bolts which will hold the outside mould together. The ideas tumble onto the page from his fertile brain.

Leonardo abandoned the traditional "lost-wax" method of casting, whereby a wax model was created over a clay core, an outer mould applied, the wax then being heated and drained off, to be replaced by the molten bronze. The worst disadvantage is that the original model is lost.

Leonardo's method was much more complex. He does not describe it fully in the Madrid manuscript, but it can be more or less reconstructed as follows. First an outer female plaster mould was to be made from the original clay model. This outer mould was then to be lined with wax or potter's clay and inside it a male mould of refractory clay was to be made.

This male mould would then be baked, the wax or clay

Photo © Royal Library, Windsor, U.K.

lining removed, and in the empty space between the two moulds a wax countermodel cast. All imperfections were to be eliminated from this wax model and then a new female mould of refractory clay was to be made over it. The wax would then be heated and tapped off, the outside mould removed, strengthened, and then refitted on the male.

The molten bronze would then be poured in.

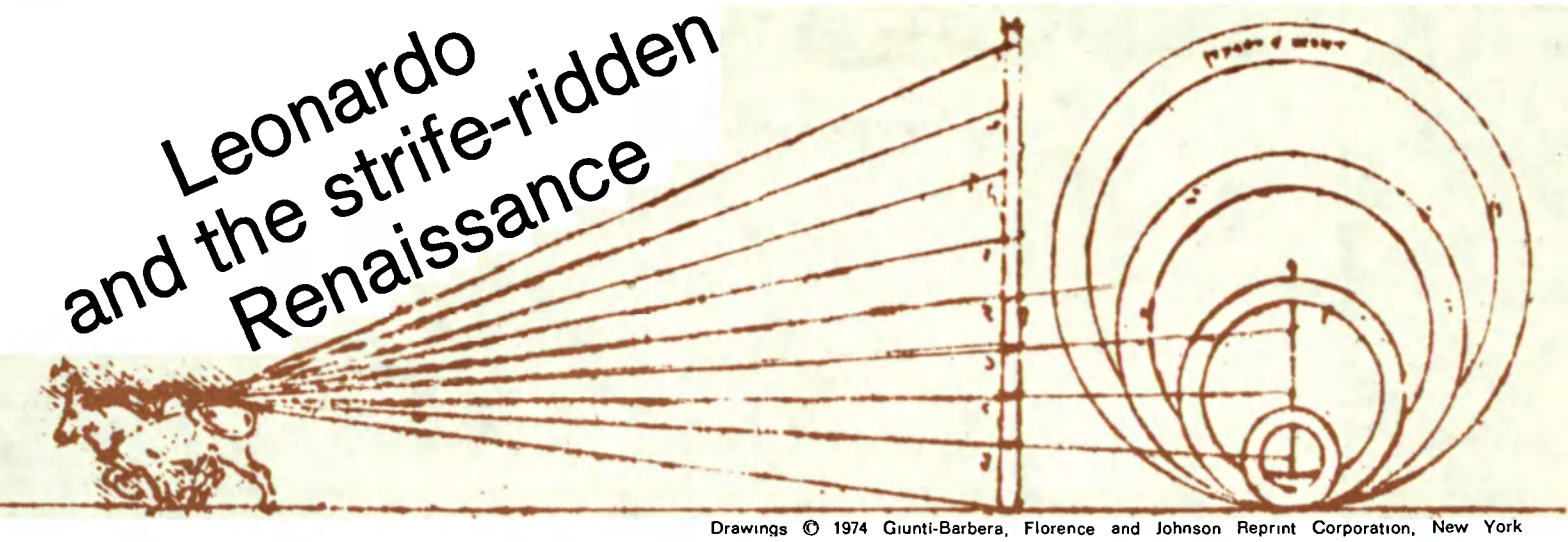
This was the new system Leonardo devised. Historical circumstances deprived him of an opportunity to put it completely to the test.

The great clay horse came to a sad end too. When the French conquered Milan in 1499, their bowmen used the horse for target practice. It cracked, and then fell to pieces. The mould was also soon lost.

It is interesting to note that some 200 years later when a huge equestrian statue of Louis XIV was constructed in Paris in 1699, the moulding and casting process used was almost identical with Leonardo's. ■

Leonardo's manuscripts are filled with countless sketches of horses, showing his unceasing study of their various postures and movements, which he drew without compromising the spontaneous quality of real horses. Many sketches, like the study of a foreleg above from the Windsor Collection in England show the minute precision with which he drew horses, dividing their bodies into sections and measuring them.

Leonardo and the strife-ridden Renaissance



Drawings © 1974 Giunti-Barbera, Florence and Johnson Reprint Corporation, New York

by Eugenio Garin

LEONARDO da Vinci spent many years of his life as a restless wanderer. After his early years in the stimulating artistic climate of Florence, his life reads like a travelogue.

In 1482, at the age of thirty, he moved to Milan to enter the service of Lodovico il Moro as an engineer, for in those days artists were considered craftsmen and technicians and it was common practice for them to be interested in and work on technical and scientific questions.

Then in the 1490s a period of change and instability began in Italy. Lorenzo the Magnificent died in Florence. France (and later Spain and Austria) invaded Italy. There was crisis in the Duchy of Milan. And in Florence Savonarola was organizing his Republican experiment.

Amidst all this turmoil Leonardo first went to work for the French, then wandered from one Italian city to another: to Mantua and the splendid court of Isabella d'Este, back to Florence, to Urbino where he was received by Cesare Borgia and then to Rome. Finally in 1516 he moved to France at the invitation of King Francis I. When he died three years later he had met and worked for some of the most exceptional men of his time and had lived through a period of renaissance art and culture in Italy and France, which was without parallel in Europe.

EUGENIO GARIN, *professor of the history of philosophy at the University of Florence, is internationally known for his studies on the culture of the Renaissance and medieval thought. He is the author of major works on tenth-century Italian culture.*

Yet, it would not be incorrect to say that in many ways Leonardo was a tragic figure. He was a man alone. He had no family (he was an illegitimate child) and had no social standing. He knew that the world was breaking up around him and that its values were being swept aside by the blind force of events. Amidst the wars and turmoil surrounding him, he plodded on with his eternal search for a supreme harmony. Death cast its shadow over everything: "I thought I was learning how to live," Leonardo wrote, "but I was learning how to die."

The lifeline which had once bound the intellectual to the city was broken. The idea of civic pride was on the wane. Political power in Italy had passed into the hands of rich oligarchies and tyrants, some mean-spirited, others able men. The intellectual was no longer a churchman. In Leonardo's time he was a layman who thought of himself first and foremost as a technician ready to offer his services to any ruler who was interested. Leonardo would offer to build a bridge across the Golden Horn for the Sultan.

Referring to himself as "the infidel called Leonardo," he wrote to the Sultan as follows: "I, your servant, have heard it said that you intended to build this bridge but that you could not do so because you could not find men capable of doing it. Now I, your humble servant, know how to build this bridge and will build it."

Leonardo also undertook to build a fortress for Cesare Borgia and a model city for the ruler of Milan, duke Lodovico il Moro. He set to work designing all kinds of machines, such as a device for flying from a mountain top and a means of underwater transport. He invented ingenious machines for use at court entertainments, and made elaborate war engines to put paid to his patron's enemies. (It didn't really matter to him who the enemies were.) As an engineer, he had a lot in common with the politician of that period who was also scientist and expert, chief among them being Machiavelli.

The legend surrounding Leonardo, as an expression of his own time and a model for all ages, began to take shape almost with Leonardo's death. Its outlines are eloquently drawn by Giorgio Vasari in the first edition of his *Lives of the Painters,* published in 1550, only thirty years after Leonardo died.

Vasari's Leonardo was a man fascinated by science, a passionate enquirer into the mysteries of science and nature, a man driven by the curiosity of a magician or an astrologer. "His capricious research led him to natural philosophy," Vasari wrote, "to study the properties of herbs and to observe the movements of the heavens, the moon's orbit and the progress of the sun." And in this first edition of his *Lives,* Vasari also added: "He developed such a heretical stance that he lost interest in religion of any sort, perhaps more interested in being a philosopher than a Christian."

However, Vasari, who was being perfectly faithful to what Leonardo had written about himself, omitted this sentence from the second edition of his *Lives,* published in 1568, in the straitened atmosphere which set in after the Council of Trent.

For Vasari, Leonardo had been the incarnation of the Ideal man as delineated by the philosophical discussion group centred on Lorenzo de Medici. "The heavens often rain down the richest gifts on human beings naturally," Vasari wrote, "but sometimes with lavish abundance bestow upon a single individual beauty, grace and ability, so that, whatever he does, every action is so divine that he outdistances all other men, and clearly displays how his genius is the gift of God and not an acquirement of human art. Men saw this in Leonardo da Vinci."

Thus Vasari was simply depicting, in his own way and according to the perspective of his times, the man that Leonardo had wanted to be. Not so much the image of himself that Leonardo presented as the character which he had delicately yet carefully fashioned for himself.

The basic premise underlying all Leonardo's work is that the artist, and above all the painter (which is how Leonardo primarily thought of himself), must understand every object he depicts if he is to be worthy of his art, since his task is to represent reality in all its facets. In other words,

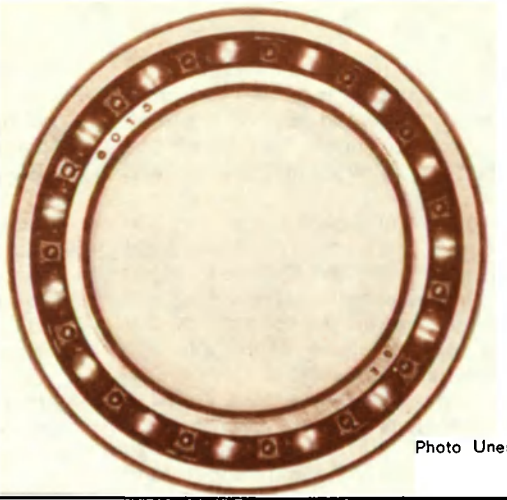
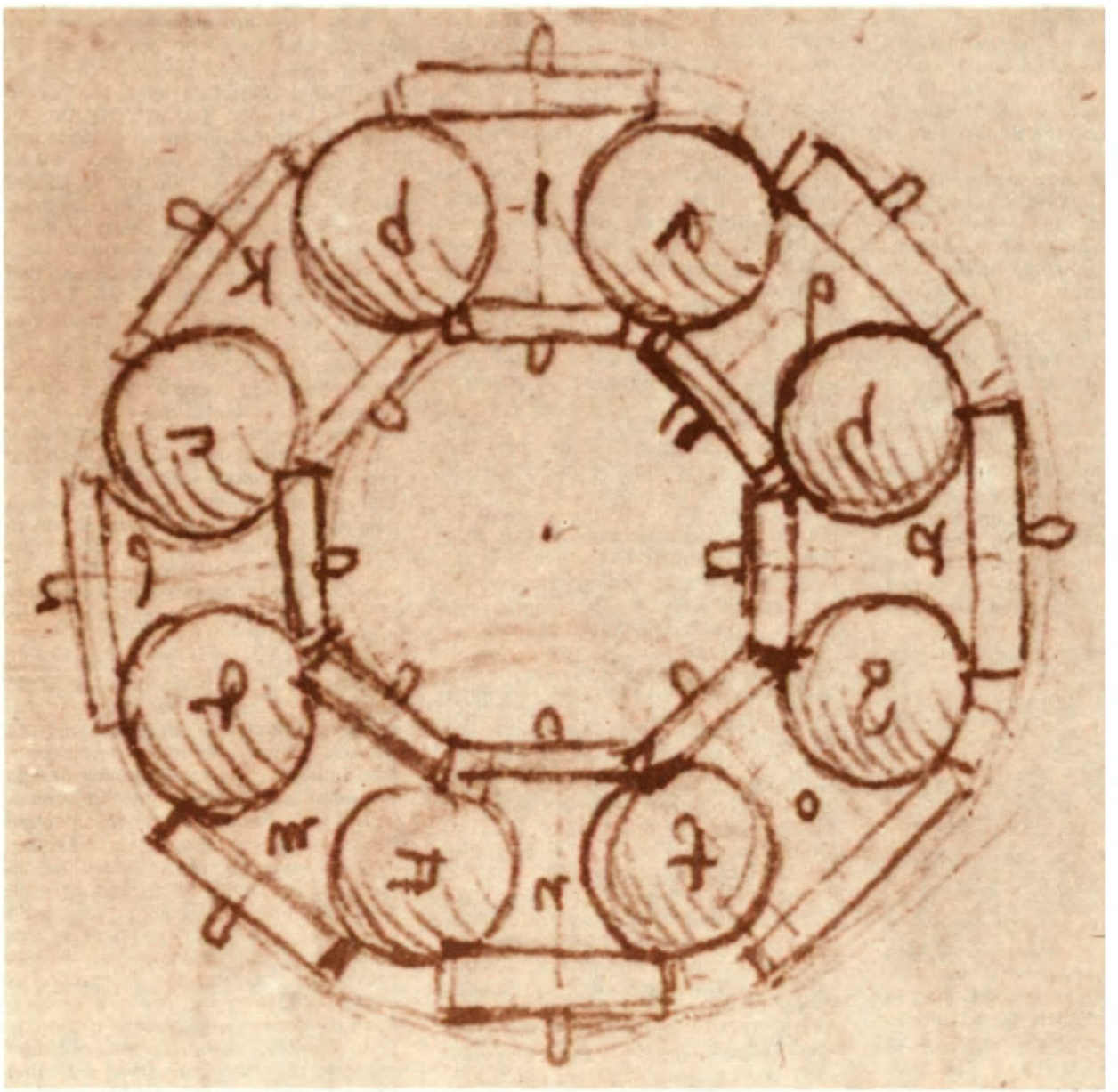


Photo Unesco Courier



Leonardo sketched this set of ball bearings in Codex Madrid I **almost 500 years ago. It bears a remarkable resemblance to the modern set of ball bearings shown above left. Leonardo understood that "if balls or rollers touch each other in their motion, they will make the movement more difficult." To solve this problem, says "The Unknown Leonardo", he put the bearings in the ring-shaped race shown here so that they could rotate freely. Top of opposite page, drawing in the** Codex Atlanticus **for studying tractive effort.**

Drawing © 1974 by McGraw-Hill Book Co. (UK) Limited, Maidenhead, England and Taurus Ediciones, S.A Madrid, Spain

he must know the whole world around him: its innermost secrets, its fundamental laws, its origins and causes. If we fail to understand this essential fact about Leonardo then we risk missing the point of his life's work.

Leonardo himself was perfectly clear on this point. He declared that the painter should be a "universal master", capable of "imitating" through art "all the different shapes which are produced by nature." The artist must "first have a mental picture" of every form. He must know the reasons for everything. He must use his intellect to master the brute force of the elements, and he must learn how to construct all kinds of machines and devices which will enable him to reproduce reality and triumph over it. "The painter," Leonardo proclaims, "is in conflict and competition with Nature;

he is the Lord and Master of Nature."

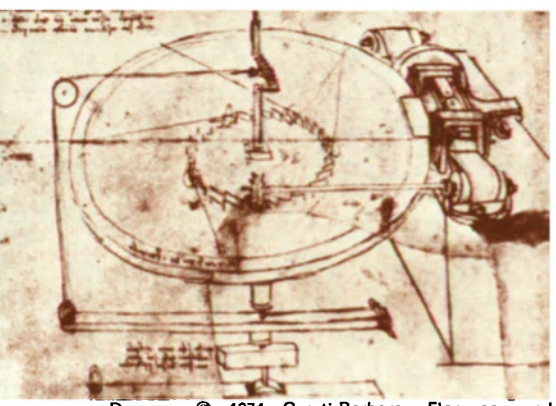
It has been said that the enormous mass of material in Leonardo's notebooks gives the impression that he intended to produce an encyclopaedia of human knowledge. It is most probable that this was indeed his purpose.

The idea was not a new one: Leonardo was acquainted with the encyclopaedias of the Middle Ages and knew Pliny's *Natural History*, which was widely read and admired during the Renaissance. And Leonardo was apparently much more aware than he lets on of what was going on in the "sciences" during this time.

The real novelty lay in his line of approach. He did not simply seek to accumulate facts and data or examples of strange occurrences for his own edification and contemplation. His purpose was action: he wanted to create, to become "Lord and Master" over Nature. And so he strained to go beyond what the senses observed and sought to apprehend the deeper forces which *act* on the senses.

It was precisely because he wanted to produce in the eyes of the beholder the effects that the real world produces, and because he wished to do so in a fresh, transfigured way, that Leonardo felt that he had to reach down into the roots of the visible world and that he had to comprehend the impulses which produce optical images.

If an artist wants to render all the possible effects of light, Leonardo reasoned, then he should learn what light actually is, study light rays and the laws governing their diffusion, the structure of the eye and the characteristics of sight. Before undertaking to carve the human form, an artist should have long practice in the dissection of dead bodies. He should be an expert in anatomy, have a good knowledge of muscular movement, and the whole process of movement in a living body.



Drawing © 1974 Giunti-Barbera, Florence, and Johnson Reprint Corporation, New York

The famous needle-sharpening machine drawn by Leonardo in the Codex Atlanticus. **He hoped that this machine would bring him "60,000 ducats a year", but it is unlikely that it was ever constructed.**

Similarly, to paint the macrocosm—that is, the world around us—the artist must study the anatomy of the universe, scrutinize its subtlest fibres and examine its every movement and manifestation.

Leonardo's notebooks are the extraordinary fragments of this great new-type encyclopaedia, based not on texts or scholastic disputes, nor indeed on superficial experiments, but instead on studies in depth into the unknown, using calculations, measurements, laws and elementary forms—which then make it possible to work back to the surface of things, to phenomena which we can understand and thereby dominate, transform and mould to our needs.

Such an encyclopaedia, as conceived by Leonardo is not unlike a great anatomical or physiological study of the universe. Just as man is a world in miniature (a microcosm) and incorporates everything contained in the universe (and hence is capable of knowing everything, and can do and become everything), so the world is like a great living organism (a macrocosm) with water instead of blood as its life-giving force, and its "causes"—that is, its mathematical laws—are its soul.

Light, motion and life—these are the fabric and structure of the universe. We see that the chapters of the encyclopaedia fall naturally into place with sections on optics, mechanics, hydraulics, anatomy, biology, physiology and cosmology. Then come the machines which enable man to rival Nature. And finally we have the crown and summit of it all, the science of painting, which Leonardo saw as fundamental and basic to the whole work. For through art, according to Leonardo, a new world is created inside the world. This is the world of man the "creator" and poet, a world which triumphs over the existing world.

The world-view which found its most extraordinary outlet in Leonardo cannot obviously be considered his own unique creation. The circles in which he moved during the first thirty years of his life had seen other distinguished artists with a broad cultural background including training in scientific as well as literary disciplines.

Filippo Brunelleschi, for example, is known to have carried on an intellectual exchange for many years with one of the greatest mathematicians and scientists of the century, Paolo Toscanelli.

Italy had also known other encyclopaedic minds before Leonardo, such as Lorenzo Ghiberti and Leon Battista Alberti. Alberti, like Leonardo, was a skilled artist. He had made a special study of physics, mathematics and optics because he felt they were indispensable for an artist.

But throughout their lives these men had preserved an attachment to their cities. Leonardo on the other hand is totally detached from the idea of the city-state (Florence, Milan); his science transcends civic and national boundaries and has no ideological or national loyalty.

Leonardo had nothing in common with the humanist "dignitaries" of his time or with the scholastics entrenched in their cities, nor for that matter with the artists attached to a particular court or belonging to a specific school. His patriotism extended quite simply to the universe, to which he belonged entirely, like his mathematics, science and philosophy.

His architectural projects fired the imagination of rulers such as Cesare Borgia, Lodovico il Moro, the King of France, and the Sultan of the Ottoman Empire. Leonardo's work is inscribed in great geometrical flourishes across the open book of the universe. Science and technology owe allegiance to neither church nor country.

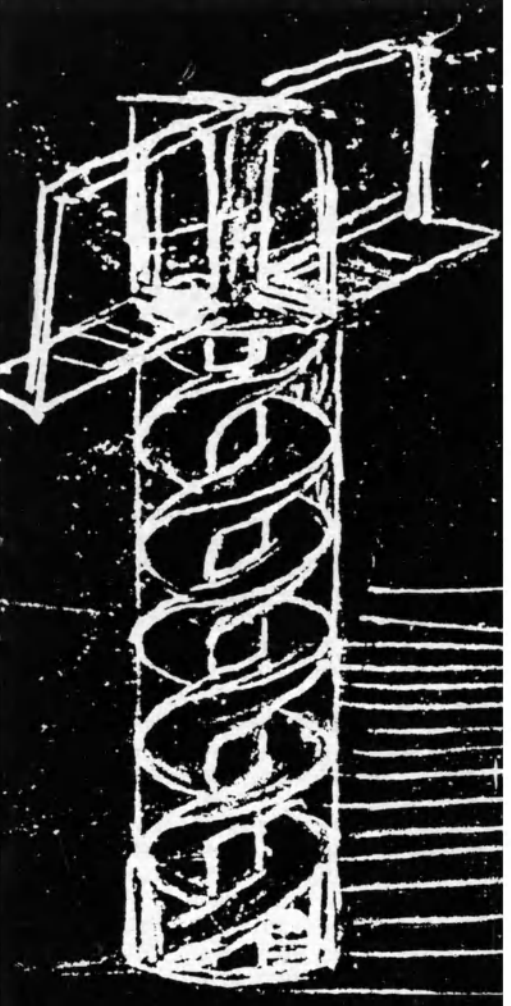
To understand Leonardo's detached attitude, his wanderings from city to city, his readiness to offer his "secrets" to the sovereigns of so many different lands, the above remarks must be kept constantly in mind. Leonardo's "secrets" were not, or not only, his exquisite paintings; they were weapons and instruments of war. But for Leonardo they were nothing more than machines that reflected man's scientific inventiveness, his drive to interpret Nature and bend it to his will. For him, these "instruments", were neither good nor evil but simply effective—in other words, they did the job required of them.

It is here, in his "detachment" as a scientist and engineer, that Leonardo parallels Machiavelli, an affinity much more significant than the fact (not without its own importance) that both men passed briefly under the aegis of Cesare Borgia in his court at Urbino.

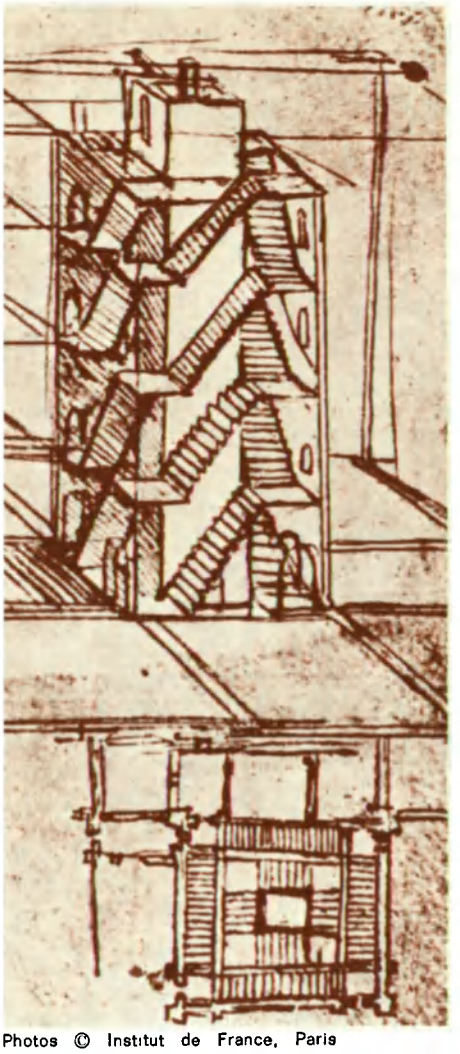
The extraordinary synthesis achieved by Leonardo reached its culmination, as we have pointed out earlier, in "painting", which for him, was charged with very special meanings. Leonardo saw the work of the painter as dominating the process of human knowledge. It was the ultimate goal of scientific enquiry and the starting point of creative endeavour. Creativity and scientific research are not two separate activities but part of the same circular process with the artist standing at the critical juncture. He is the meeting point between knowledge and action. More precisely, where knowledge is transformed into creation.

It is no accident if Leonardo extols the painter for he always attributes special importance to the eye and the act of visual perception, as well as anything having to do with the world of images.

Leonardo always tended to express



Leonardo's notebooks contain many drawings, diagrams and architectural plans for an "Ideal City" In a manuscript now at the Institut de France, Paris, Leonardo writes that "A building should always be detached on all sides in order that its true shape may be seen." Leonardo wanted the inhabitants of his ideal city to enjoy as much privacy as possible and to this end devised ingenious access systems by staircase: above right, building with quadruple staircase, and, above, a double spiral staircase designed for the "Ideal City". In Codex Madrid II Leonardo drew many architectural studies and sketches, using his ideas on private corridors and staircases to design a castle in which the lord could see what was going on in the building.



Photos © Institut de France, Paris

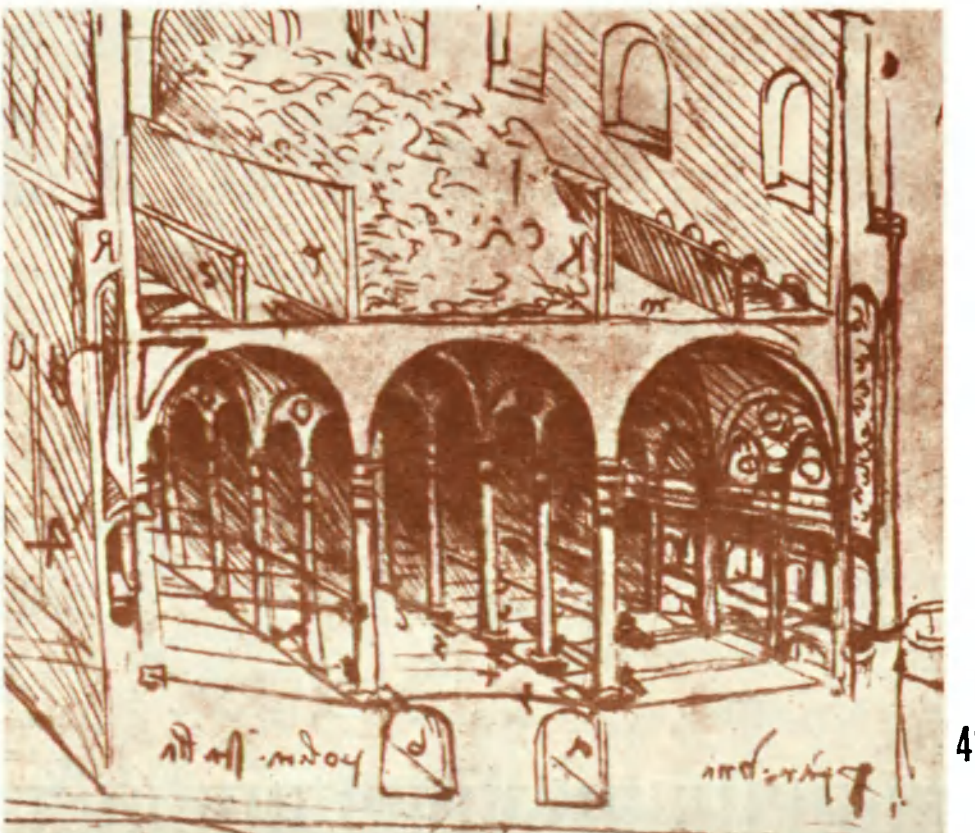
his ideas in visual terms: "The painter," he wrote, "should resemble a mirror." He should welcome "the multiplicity of things," not just their external forms, but also their inner properties and essence, and their elementary geometric patterns, which stand at the roots of perceptual experience and allow us to understand it.

Hence the primacy of mathematics over the evidence of the senses: "no human enquiry can properly be called science unless it passes by way of mathematical reasoning," said Leonardo. Hence too the "philosophical" importance of painting: "Anyone who feels contempt for painting has no real affection for philosophy . . . Painting itself is philosophy because it captures the movement of bodies through space in their full spontaneity. And philosophy does exactly the same thing . . . "

These two aspects of human activity, knowledge and action, "seeing" and "creating", cannot, therefore, be separated. The circular process—science-engineering-art and seeing-doing—is a single unique activity.

For Leonardo, the invention and construction of machines underscore a number of important considerations: (1) that technology and science are inseparable, the two being linked by the "mathematical" structure of all ▶

Leonardo designed a stable with automatic mangers which would not be out of place on a 20th-century farm (drawing below is from a manuscript in the Institut de France). The hay in the loft is fed "to the mangers, by means of funnels, narrow at the top and wide over the manger". Leonardo also designed a 220-feet-long stable capable of housing 128 horses.



Below, detail of Leonardo's drawing of the "Ideal City" which appears in a manuscript now at the Institut de France, Paris, showing its high and low level roads. Lower photo, model of the Ideal City in the Milan Science Museum, reconstructed from Leonardo's drawings and notes. Leonardo wrote that "By the high streets no vehicles and similar objects should circulate, but they are exclusively for the use of gentlemen. The carts and burdens for the use and convenience of the inhabitants have to go by the low [streets]." In his plans for the city, Leonardo is exclusively concerned with social and hygienic goals, unlike most architects of his time.

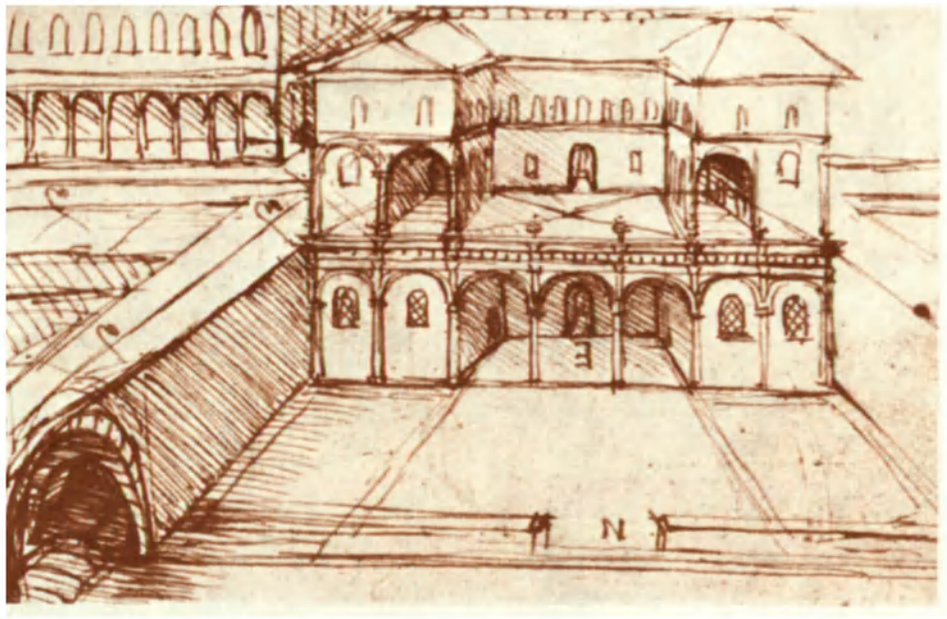


Photo © Institut de France, Paris

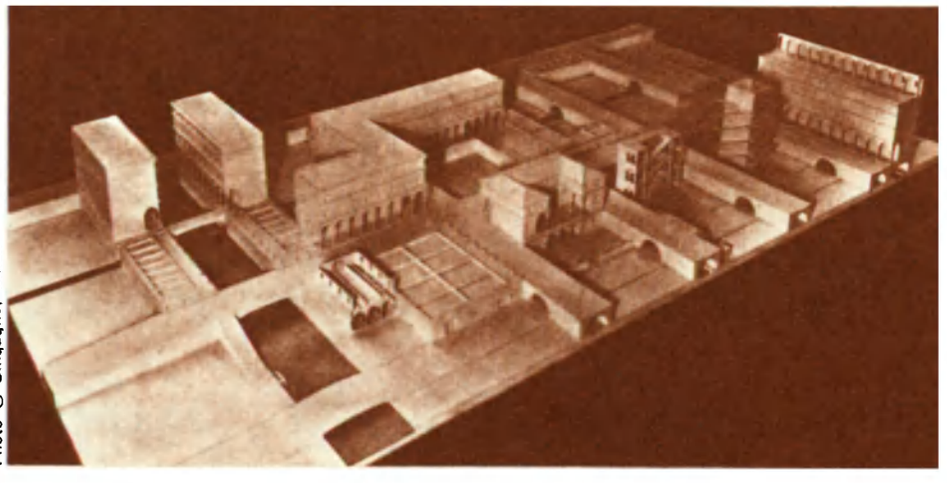


Photo © Singaglia, Milan

One of Leonardo's grandiose projects was the bridge across the Bosphorus from Constantinople to Galata which he offered to build for the Sultan of the Ottoman Empire. Right, above, drawing of this bridge from above and in elevation, from a manuscript in the Institut de France. Leonardo notes the length, 1,150 feet. Model, right, below, by a modern Swiss scientist, D.F. Stussi proves that the plans were technically feasible.

Photo © Institut de France, Paris

Photo © Science Museum Milan

things; (2) that the skeletal framework of physical objects can be reduced to a mechanical model; (3) that there is a fundamental connexion between mechanics and real life; (4) that research into models based on visual observation shows that "the eye is the least fallible of all the human senses."

From all this we can clearly see the perfect unity that existed in Leonardo's encyclopaedia, in which it is absurd to separate science, technology and art. Vasari's mistake was to break, or rather misunderstand, the close link between these three domains, with the result that he failed to see the real significance of the work, and finally concluded that it was an example of Leonardo's madness and incoherence.

"He perpetrated many such follies," Vasari wrote, "he studied mirrors and made curious experiments to find oil for painting... His knowledge of art, indeed, prevented him from finishing many things which he had begun, for he felt that his hand would be unable to realize the perfect creations of his imagination, as his mind formed such difficult, subtle and marvellous conceptions that his hands, skilful as they were, could never have expressed them..."

Vasari referred to these activities of Leonardo as "caprices". But in reality they were part of an unending search for the unifying factor in human experience, for a meaning of the created universe, for man's place in the world. Here was the restless beginning of a new era, a new way of understanding art and science.

Each of Leonardo's thousands of manuscript pages, with their awesome entwining of fragments of minutely detailed prose and delicately refined illustrations, strange machines and precisely sketched anatomy, not only symbolizes man's perennial dreams and aspirations but also expresses a totally new way of considering man's task on earth—as an endless search to master the transient stuff of reality.

I have taken care to stress Leonardo's extreme refinement in everything (whether it be his hand-writing or the disdain he showed for the *literati*). He was an exquisitely literate man, and we know from the Madrid notebooks that he possessed a rich and widely diverse library.

All of Leonardo's "caprices" are justified by an awareness that man and his works are fragile. And here perhaps is the sign, and the secret, of Leonardo's relevance for all of us today: the fact that he understood and expressed with superlative skill the enigmatic insecurity of man and the mystery of his destiny and condition, at a time when unforeseen and unforeseeable possibilities were opening up in art and science. ■

Eugenio Garin

THE GLORY OF PAINTING

Reflections on art in the Madrid II Manuscript

by Carlo Pedretti

Photo © Royal Library, Windsor, U.K.

Photo © Anderson-Giraudon, Paris

Leonardo defined his whole approach to art in Codex Madrid II. "Do not make the muscles of your figures apparent", he writes, "because even if they are in their right places they do not show prominently unless the limbs in which they are located are exerting great force or are greatly strained." He criticizes "barren and woody figures" and applies the phrases "bag of nuts" and "bunch of radishes" to nudes that are "woody and without grace." Leonardo attacked many artists who were guilty of this abuse, and in a manuscript dating from 1513-1514 (known as "Manuscript E", at the Institut de France in Paris) his imprecation appears to be a criticism of Michelangelo's nudes in the Sistine Chapel, in Rome. Above left, red chalk nude by Leonardo (about 1503-1504). Above right, Adam and Eve expelled from Paradise, detail of a fresco by Michelangelo on the ceiling of the Sistine Chapel (1508-1510).

"LIMBS which are not in exercise must be drawn without showing the play of muscles. And if you do otherwise, you will have imitated a sack of nuts rather than a human figure."

This is one of the notes on painting found in the second of the recently discovered Madrid Manuscripts of Leonardo da Vinci dating from the first years of the 16th century. It is of great interest because it illustrates how Leonardo and Michelangelo differed sharply in their approach to depicting the human form, particularly as portrayed in Michelangelo's Sistine Chapel frescoes (1508-1510). For ▶

CARLO PEDRETTI *is the author of many books on Leonardo. The latest, "Leonardo: A Study In Chronology and Style", was published in 1973 by Thames and Hudson, London. He is a professor in the Department of Fine Arts at the University of California, Los Angeles. This article is inspired by a chapter on the "Notes on Painting in the Madrid Manuscripts" published in Italian in his book "Leonardo da Vinci Inedito" (Leonardo da Vinci's unpublished works), published by Barbera Editore, Florence, 1968.*

An eye of the angel in The Virgin of the Rocks, **executed by Leonardo in Milan about 1483 (Louvre Museum, Paris).**

An eye of Mona Lisa. **Leonardo began work on the painting about 1501 and finished it more than four years later (Louvre Museum, Paris).**

Leonardo, the human body was not an excuse for the artist to show off his skill in depicting bulging muscles unnecessarily.

This and the other notes on painting in *Codex Madrid II* were written at a crucial moment of Leonardo's career, and as such they reflect the innovations in the artistic theories of the Cinquecento (16th century).

It is no longer the appearance of things that Leonardo is concerned with, but their structure, so that he adopts a type of drawing which moves away from atmospheric effects to stress form: form which is defined by sharp contours and by lines of shading which curve around it with deliberate slowness.

It is no longer the Florentine gracefulness of the late Quattrocento but a more heroic and herculean sense of proportions which is reflected in his anatomical studies, and in the studies for the warriors of his *Battle of Anghiari*, which appear to conform, like a silent homage to Masaccio, to the example provided by Michelangelo with his *David*, completed in 1501.

Form is expressed by style; and by style I mean not only Leonardo's art but also his thought as expressed by words, for there is a close affinity between his writing and his drawing. An example is given by a text already known, in which Leonardo tells the painter how to retain the images of human figures in action by using essential lines, something like shorthand.

"In order to draw a head," says Leonardo, "make an O, for an arm make a straight or bent line, and do the same for the legs and bust, and when at home turn such notations into perfect form."

However, our eye does not need to "turn" those notations into "perfect form"; on the contrary it is able to perceive the impulse that has guided the artist's hand, and it is undoubtedly seduced by the open touch, which leaves much more to the imagination.

The notes on painting in Leonardo's *Codex Madrid II* pertain not only to the human figure but also to the problems of light, shadow, and colour.

On one page Leonardo brings together two major aspects of pictorial vision: the representation of colour "in perspective", (that is, the colour of objects as it is affected by intervening atmosphere and therefore varying in intensity according to the distance of the objects), and human movement.

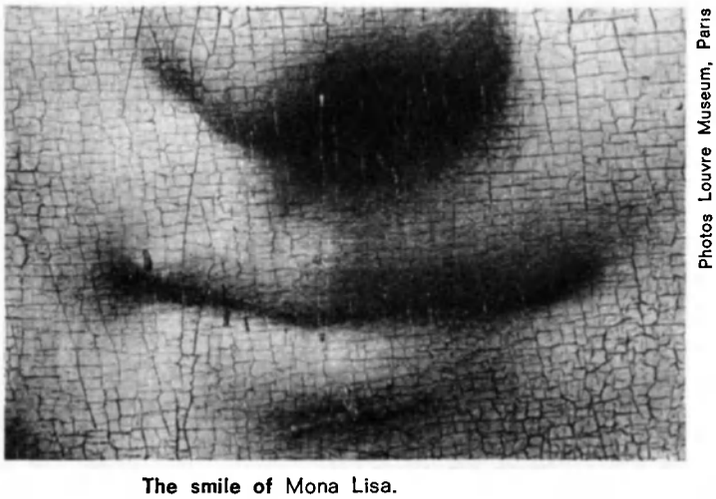
These aspects are further elaborated in other parts of the manuscript, and while the first is treated with a considerable degree of abstraction which can only be explained with the language of the diagram, the second is exemplified by quick notations of the human figure in action.

Some of them recall the sketches for the *Battle of Anghiari*—drawings of an energy which approaches fury, done with an explosive line, such as the one at Windsor in which Leonardo juxtaposes the screaming expressions of men and animals, lions and horses. This is a sheet of thoughts, more than the definite path of an idea for composition: a search for the expression of human bestiality in war.

In *Codex Madrid II* one can see how optics is closely related to painting. One example: "The surface of every opaque body takes on the colour of the object opposite to it. But green subjects, such as meadows and other such things should be arranged opposite the shadows of green bodies, according to art, so that the shadows that take on the colour of such an object do not lose their quality and appear to be the shadow of a body other than green; should you put bright red facing a green shadow, the shadow will become reddish of a most ugly colour, and will be very different from the true shadow of green."

Most interesting here is the advice given to the painter to make colour juxtapositions "according to art", so as to achieve the kind of harmony that derives from retaining in

The smile of the angel in The Virgin of the Rocks.



The smile of Mona Lisa.

Photos Louvre Museum, Paris

An eye of St. John the Baptist, painted by Leonardo about 1509 (Louvre Museum, Paris).

An eye of the lady in the portrait known as the Belle Ferronnière. (Louvre Museum, Paris.)

WHEN LEONARDO EYES ARE SMILING

In Codex Madrid II, Leonardo states that the human face and body are defined by the light surrounding them. He notes that reflected and refracted light as well as coloured shadows are all what he calls "the truth of colours". This may explain the affinity between the many faces he painted which the photographic enlargements on this double page clearly reveal, especially Leonardo's rendering of the eyes and the smile. The enlargements show how skilfully Leonardo played with light and shadow in order to achieve his enigmatic smile and beautifully expressive eyes (thousands of pages have been written about Mona Lisa's smile). In Codex Madrid II, Leonardo advises the painter to strive for a subtle blend of shadows which he describes as "the gracefulness of shadows, smoothly deprived of every contour". By so doing he has given us his secret of how he achieved such delicately nuanced forms in his models.

a shadow the colour of its object (Leonardo refers to the "true shadow") and by avoiding what he calls "very bad shadows", which are those affected by the reflection of another object of different colour, as would be the case with a green object that comes to produce a reddish shadow.

All the elements of Leonardo's painting are present in the theories expressed in the Madrid Manuscript. Another series of notes, in addition to those on form and colour, deals with light and shadow and the smooth transition from light to shadow, which is the true essence of the famous Leonardo *sfumato*. The notes on this subject in the newly discovered manuscript are numerous, but it is interesting to note that each one takes into account the element of colour.

When in the first period of his activity Leonardo was dealing with the problem of light and shadow he conceived of objects in terms of geometrical entities and was mainly concerned with the study of the gradations and degrees of intensity of the shadows.

After 1500 his major concern becomes the study of light and shadow on objects placed in the open air, thus taking into account colour and reflections. Light becomes the vehicle that blends the elements of landscape into a harmony of transitions from colour to colour, and this Leonardo calls "grace".

The human figure too becomes part of the landscape (one thinks of the *Mona Lisa, The Virgin and St. Anne, Leda)* and thus participates in the phenomena of reflection, refraction, and interplay of coloured shadows, as is the case with every other object placed under the light of the sky. What can be seen under the projection of a roof is also to be seen under the chin of a human face.

One of Leonardo's most beautiful observations pertains to the way a human face should be represented. He advises the painter to arrange the setting so as to achieve the most delicate *sfumato* effects in the shadows, what he ▶

The smile of St. John the Baptist.

The smile of the lady in the Belle Ferronnière.

calls "the gracefulness of shadows, smoothly deprived of every sharp contour."

The setting is provided by the walls of the houses flanking a street, through which the light penetrates—light made of air without brightness, a golden, diffuse light such as that of Giorgione.

Now, says Leonardo, "light ends upon the pavement of the street and rebounds with reflected motion at the shadowy parts of the faces, brightening them considerably. And the length of the aforementioned light of the sky created by the boundaries of the roofs hanging over the street illuminates almost as far as the beginning of the shadows which are underneath the projections of the face, and so it is gradually changed into brightness, until it ends over the chin with imperceptible shadows all over."

It is a widely accepted opinion that Leonardo was insensitive to colour and that for him the "glory of painting" lay only in the effect of relief that it can produce. The chronology of his notes on painting shows that this may apply to the first period of his theoretical work, when his art was still bound to the teaching of the Florentine school of the Quattrocento.

But after 1500 his observations on colour gradually intensify to a point where his theories have no application in any of his works which have come down to us. It is enough to mention the effects of violet light at sunset, a light that he designates as being of the colour of the lily and that makes the landscape "most cheerful and pleasant."

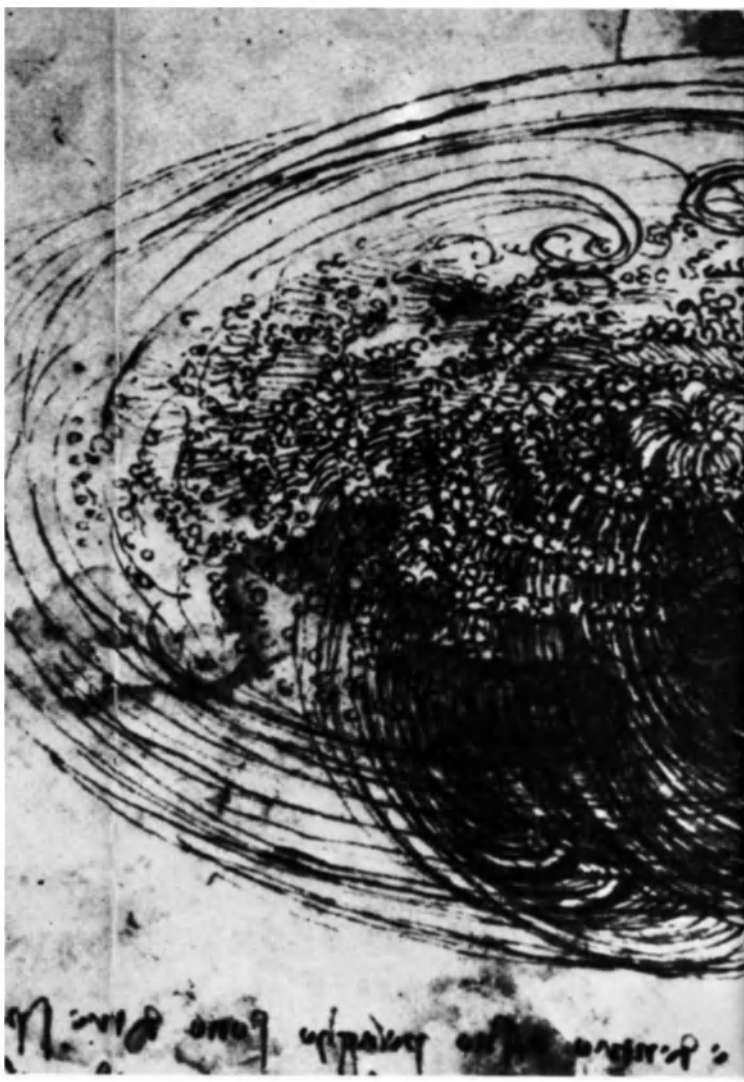
"The beauty of colour," concludes Leonardo, "is to be found in the main lights." Light is taken as a symbol of virtue, and the "truth of colours" is the beauty that light reveals in them.

What is most interesting in this case as in many others is what the British would refer to as the "unpredictable Leonardo", the Leonardo who cannot be anticipated, because the notes he writes are nothing but the record of the movements of his mind, so that his precepts to the painter do not have the stiffness of academic teaching but the freshness of a revelation.

But enough of comments, explanations, and interpretations! Leonardo's words come to us with the precision of mathematics and yet they are evocative of the space that opens up in the background of his paintings:

"What I would remind you of, concerning faces, is that you should consider how, at varying distances, different qualities of the shadows are lost and that only the main spots are left, that is, the pits of the eye and the like: and finally that the face remains dark, because the lights, which are small compared with the medium shadows, are absorbed by darkness. For this reason, at a distance, the qualities and quantities of the main lights and shadows are consumed, and everything blends into a medium shadow. And this is why trees and all objects appear darker at a distance than if the same objects were near the eye. From this obscurity on, the air which is between the eye and the object causes the object to become brighter and to turn towards blue. But it turns bluish rather in the shadows than in the luminous parts, where one can see better the true quality of the colours." ■

Carlo Pedretti



Photos © Royal Library, Windsor, U K

Study of Star of Bethlehem amid twirling grasses, with leaves of crowsfoot and wood anemones, and flowers of spurge. Drawn as part of a study for Leonardo's Leda.

Photo © Taken from "Leonardo and the Age of the Eye" by Ritchie Calder, Heinemann, London, 1970

Drawing of a rearing horse executed by Leonardo in 1504 for his never-completed mural, The Battle of Anghiari. Even the cartoon of this ill-fated work has been lost, although many preliminary sketches of the work have survived.

Whirling movements of every kind fascinated Leonardo. He likened the eddies of whirlpools, which he called "the cosmic breathing of the ocean", to the "lake of blood extending through the human body". He saw a parallel between water and hair. "Observe the movement of the surface of water", he wrote, "how it resembles hair, which has two movements, one of which comes from the weight of the hair, the other from the curves of the curls. Thus water has its whirling curls, some of which follow the rush of the main current, while others have a movement of incidence and reflection". Leonardo's scientific drawings of water in motion are veritable works of art. Above, a shaft of water pouring into a pool forms a chrysanthemum-like image of bubbles and dancing lines.

Study of hair arrangement for Leda and the Swan, a Greek myth which inspired Leonardo to produce a painting, now lost and known only from preliminary sketches and 16th century copies.

Photo © Royal Library, Windsor, U K

(Continued from page 7)

edition of Leonardo's unpublished writings.

However, Count Libri could not resist the temptation of removing a number of leaves from the Leonardo notebooks which he studied at the Institut de France. Libri was a sharp businessman and he set about selling the manuscripts he had appropriated.

Some of the stolen manuscript pages found their way to England, while the small Codex on *The Flight of Birds* was purchased for 4,000 lire by a certain Count Manzoni, who later sold it to an eminent Leonardo scholar, Theodore Sabachnikoff. Meanwhile, the directors of the Institut de France became suspicious of Libri, the only person who had been in a position to consult the Paris manuscripts. Libri denied the theft energetically, but the evidence against him was overwhelming, and he was sentenced (in his absence) to ten years' imprisonment. After this scandal, the Leonardo pages that had illegally crossed to England were returned to the Institut de France, and Sabachnikoff handed over *The Flight of Birds Codex* to the Biblioteca Reale in Turin, where it still is today.

The story of the main changes of ownership of the Leonardo notebooks might have ended there. However, at the beginning of 1967 came official news of an astonishing find : two Leonardo notebooks previously considered lost had been discovered in the Madrid National Library.

After an initial reaction of justified amazement, people began to ask how these two manuscripts could have turned up in Madrid. Scholars have come up with the following answer. Some of the Leonardo material owned by Pompeo Leoni was sold in Spain after his death. One of the purchasers was probably Juan de Espina, a Madrid collector. Between 1620 and 1630 first the future Charles I of England (then the Prince of Wales) and later the Florentine Vincenzo Carducci visited de Espina and saw his collection. Both visitors were particularly impressed by two books "written and drawn by the great Leonardo da Vinci."

When de Espina died in 1642, he left his precious collection to the King of Spain. The legacy included the two Leonardo books, and these were then deposited in the Palace Library, which around 1830 became the nucleus of Spain's recently founded National Library. It is highly likely that the two recently discovered notebooks are the two manuscripts which once belonged to de Espina.

In a nineteenth-century printed catalogue of the Madrid National Library, there is a reference to two Leonardo "autographs". However, everyone who followed up this reference and asked to consult the precious manuscripts was disappointed. Other manuscripts were found at the shelf-marks given in the catalogue, and there was no sign of the Leonardo autographs.

At the end of the 19th century, a Florentine bibliophile named Tammazo de Marins tried to find the manuscripts in the Madrid Library, but he

This drawing from the Codex Atlanticus suggests that Leonardo envisaged a form of water skiing. However, these floating shoes and supporting sticks were never made, and we do not know what material he intended to use to make them buoyant.

Drawing © 1974 Giunti-Barbera, Florence, and Johnson Reprint Corporation, New York

was unsuccessful and the Library's directors decided to consider the two volumes as definitely lost.

Then, in 1964, an eminent French Leonardo scholar, André Corbeau, expressed his conviction that the two manuscripts were in fact in the National Library and that their failure to come to light might well be due to an error in the printed catalogue. At this point the Library's directors decided to make another attempt to locate the two notebooks.

This time the search was successful. At the beginning of 1965, Don Ramon Paz y Remolar, the director of the manuscript section of the Library, had the immense surprise of finding the Leonardo volumes, not at the shelf-marks given in the nineteenth-century catalogue (Aa 19 and 20), but at shelf-marks Aa 119 and 120.

The news of this important discovery spread by word of mouth through the world of scholarship. In 1967 the news was officially confirmed, and today the massive contribution to our knowledge of Leonardo's work provided by these new manuscripts is at last being made available to the public in a facsimile edition to be published this autumn by McGraw-Hill Book Company of *Codex Madrid I* and *Codex Madrid II*, as they are now called.

Another event of the last few years which can be compared without excessive exaggeration to the discovery of a new manuscript is the restoration of the *Codex Atlanticus* belonging to the Ambrosian Library in Milan.

The man behind this great project was Cardinal Montini, Archbishop of Milan, now Pope Paul VI. In 1962 he successfully urged the directors of the Ambrosian Library to send the precious Codex to be restored at the Convent of Grottaferrata near Rome. The idea was not only to conserve the *Codex Atlanticus*, but to salvage as much as possible from the disastrous scissors-and-paste job carried out by its compiler, Leoni, who had arbitrarily gathered together whatever he thought related to mechanics in the Leonardo papers and notebooks belonging to him.

Leoni had taken large sheets of thick white paper (the size used for atlases, hence the title *Codex Atlanticus*), and used them as a backing on which to "stick" the original pages by Leonardo, which were considerably smaller and often covered from top to bottom with sketches and writing. Some of Leonardo's pages were covered with drawing and writing on just one side of the paper. In these cases, or whenever Leoni considered the handful of notes and hurried sketches on the verso of the paper to be unimportant, he stuck the verso directly on to the backing page.

When, however, Leonardo had covered both sides of the paper with notations and drawings, Leoni made a kind of window in the backing page so that both recto and verso were visible. Finally, when dealing with large-sized Leonardo pages, Leoni adopted yet another system : he folded the page in two, introduced a window in the backing page on which he mounted one of the two halves, and left the other half of the Leonardo page hanging folded just as it was.

Leoni's barbaric treatment of the manuscripts had unfortunate results. A large number of verso sides on which Leonardo had recorded his thoughts are lost. The margins of the pages which have been pasted on to "windows" are also lost, and these often contained parts of a drawing or the continuation of writing. Thirdly, in the case of the large pages folded in two, the part left hanging has often been torn off and consequently has disappeared.

The restoration carried out during ten years of devoted work at Grottaferrata has entirely altered the appearance of the *Codex Atlanticus*. In many ways it is now a completely new document. The restorers used the most advanced techniques. For example, the Leonardo originals were scrupulously washed and toughened with sophisticated modern fibres and chemicals in order to make them more resistant to the ravages of time.

Today, as a result of this great enterprise, the *Codex Atlanticus* consists of 1,068 pages, divided into twelve leather-bound volumes.

There was no question of letting the newly-restored Codex be used for consultation, and so a facsimile edition of it is being produced by the Florence publishing house of Barbera. The first volumes, the end-product of refined technology and painstaking collation with the original, have already been published, and the *Commissione Nazionale Vinciana* is at present preparing more transcriptions of the Codex, which will thus soon be available to Leonardo scholars in its entirety.

Thus modern scholars and restorers have done much to repair the havoc wreaked on Leonardo's manuscripts and we can now appreciate more fully the activity of one of the most powerful and universal minds the world has ever known.

Paolo Galluzzi

Just published

Three Centuries of Scientific Hydrology

123 pages 25 F. quadrilingual (English, French, Spanish, Russian).

● Leonardo da Vinci thought that sea water rose from within the earth to the heights of mountains, like blood rising from the lower regions of the human body to the head;

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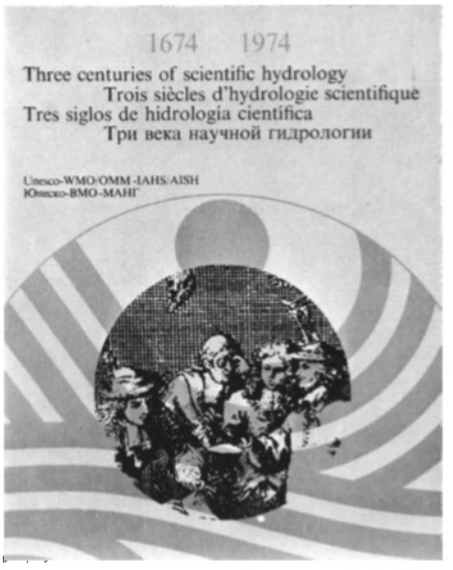
● The Chinese recorded rain, sleet, snow and wind as far back as 1200 B.C. and used rain gauges as early as 1000 B.C.;

● Ancient Egyptians noted flood heights and forecasted the flood waters of the Nile before 3000 B.C.



These are just a few of the examples of man's historical concern with water as a major force in the development of civilization. But hydrology as a science was born in 1674 with the study by Pierre Perrault which paved the way for the universal recognition of the water cycle as we know it today.

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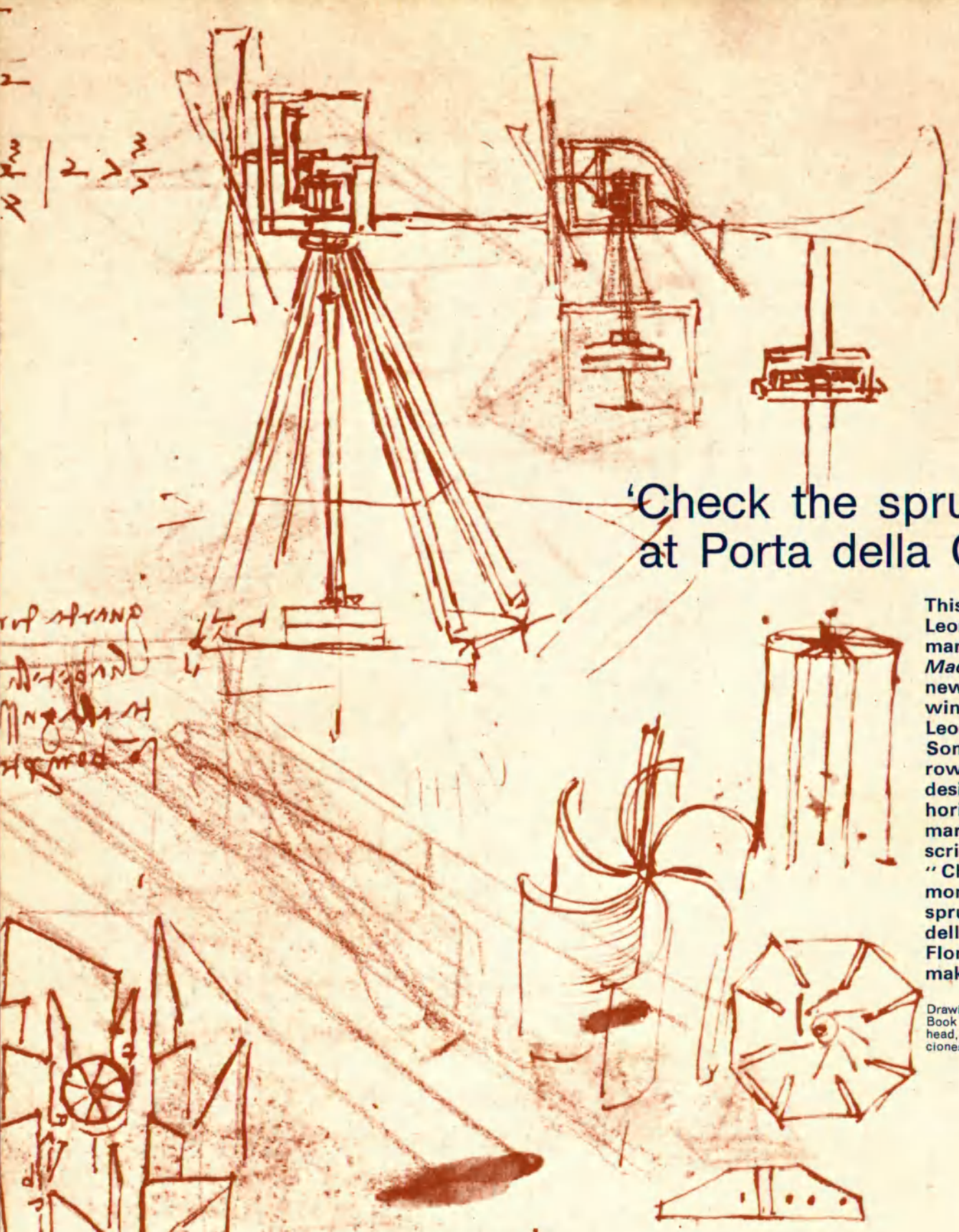

'Check the spruce trees at Porta della Giustizia'

This is a page from Leonardo's rediscovered manuscript *Codex Madrid II*. It shows new designs for windmills which Leonardo worked out. Some of them (bottom row) had sails designed to rotate horizontally. In the margin Leonardo scribbled this note: "Check tomorrow morning whether the spruce trees at Porta della Giustizia [in Florence] are good for making such a mill."

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